THE GOLDEN NEMATODE HANDBOOK
Survey, Laboratory, Control, and Quarantine Procedures

By
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Agriculture Handbook No. 353

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Service

Washington, D.C. Issued September 1968

For sale by the Superintendent of Documents, U.S. Government Printing Office,
Washington, D.C. 20402—Price $1.25

FOREWORD

The history of nematology in the United States is characterized by its rapid growth and by general recognition by growers, industry, and agricultural workers of the importance of nematodes in limiting crop production.

The first regulatory activity against nematodes was in 1926 when the U.S. Department of Agriculture's Bureau of Entomology and Plant Quarantine imposed regulations against the bulb and stem nematode. Today, several hundred Federal and State people are engaged in regulatory nematology and are spending about $4.5 million a year on surveys, enforcement of quarantine regulations, and the application of nematocides.

Before World War II, about 35 people were engaged in nematological research, and the annual appropriation was less than $150,000. Today, at least 175 persons are working full or part-time on nematological research, and the annual expenditure is about $4 million.

The discovery of the nematocidal properties of dichloropropene-dichloropropane in 1943 marked the beginning of the present soil fumigation industry. For the first time farmers and nurserymen had a practical and economical means of controlling nematodes. About the time of this discovery the golden nematode was found on Long Island (1941). Although a handful of nematologists in the United States had been working on the nematode problem for a number of years, the discovery of the golden nematode brought the problem forcibly to public attention.

In 1953, nematologists discovered that the burrowing nematode, *Radopholus similis,* caused spreading decline of citrus, and in 1954, they discovered that the soybean cyst nematode, *Heterodera glycines,* was causing economic losses to soybeans.

After the discoveries in 1941, 1953, and 1954, survey, regulatory, and control programs were initiated and special methods were developed for large-scale control programs.

Regulatory measures and the laboratory and field techniques used to carry out the program against the golden nematode are described in this handbook. Most of the methods are suitable for use on a large scale and are applicable to most other cyst nematodes. No other publication includes such a comprehensive treatment of a nematode control program. The information will be valuable not only to those conducting regulatory and control programs involving the golden nematode, but also to agricultural administrators, plant protection officials, and students in many other areas of agriculture.

Joseph F. Spears is well qualified to write this handbook. He was one of the organizers of the program. He pioneered in the development of many of the program operations and has been associated with the work in some capacity for more than 20 years. He initiated the present chemical control program. In addition, he has had broad experience with large-scale plant protection programs involving other nematodes and other organisms, such as insects and fungi.

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PROTECT

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PREFACE

This handbook has been prepared to meet the needs of agricultural workers interested in the protection of crops from nematode outbreaks. Most of the procedures set forth in this handbook are the outgrowth of research conducted by the New York State College of Agriculture, Cornell University, and the Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA). These methods and procedures have been successfully used for several years. Through the efforts of the scientists working on this problem these methods are constantly being improved.

Many people have contributed in various ways to make this handbook possible. The author is sincerely grateful to all of them. Special acknowledgment is made to personnel of the New York State Department of Agriculture and Markets; the Department of Plant Pathology, Cornell University; the Nematology Section of the Crops Research Division and the Plant Pest Control Division, ARS, USDA; and the Foreign Agricultural Service, USDA.

CONTENTS

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INTRODUCTION

The golden nematode is undoubtedly the most serious pest threatening the American potato industry. It is recognized throughout the temperate regions of the world as one of the most difficult of all crop pests to control. It also attacks tomatoes, but it is not a major threat to this crop.

The golden nematode is the subject of stringent quarantine regulations in most countries where it occurs. Countries not known to be infested have rigid regulations governing the importation of potatoes or other products that might carry the pest. Agricultural officials in countries where the nematode occurs agree that potatoes cannot be grown economically on land containing large numbers of the nematode. Tuber yields of less than seed planted have been reported from fields heavily infested.

The golden nematode poses many problems in its control. It has a remarkable ability to survive under unfavorable conditions. It can remain dormant in the soil in the absence of host plants for many years because the unhatched nematode is protected by both the shell of the eggs and the durable cyst wall, which acts as a protection against adverse conditions. The lack of any one aboveground symptom to betray its presence is an aid to its survival. Thus, light or scattered infestations of the nematode reproduce and increase in the soil undetected. During this time of buildup, infestations may spread to new fields, and because the populations are low they will not be detected by the best survey techniques. This type of spread and slow buildup of populations is undramatic, and low levels of infestations are always one step ahead of survey. Crop reduction as a result is negligible. The buildup may require 5 to 7 years or more after introduction of the pest into a field before noticeable crop injury and reduction in yields occur. However, buildup of nematode population increases like compound interest until the crop is destroyed.

As the damage caused by plant nematodes is becoming more widely recognized, general interest in the problem is increasing and a mounting volume of questions are being asked by growers. Most countries now have nematologists devoting their efforts to problems caused by plant nematodes. More and more surveys are being undertaken in many countries to determine distribution and identification of plant nematodes.

Control of the golden nematode in most areas of the world still depends on crop rotation. However, scientists have been devoting more and more attention to the development of resistant varieties. Resistance-breaking biotypes of the golden nematode have now been reported from several countries, and investigators are devoting much attention to the influence this has on the problem.

The use of nematocides to control the golden nematode is also being investigated by workers in several countries. Some European countries are making limited use of these chemicals. However, the high cost of chemicals has been a factor in preventing large-scale use.

In the United States the use of nematocides is increasing annually for nematode control on many crops. Over 100 million pounds of nematocides are used annually in this country, principally on tobacco, pineapple, and vegetable soils. Nematocides are applied to about 1 million acres. In the United States and Canada, the use of nematocides has been adopted on a large scale in an effort to eliminate the golden nematode.

Continuing research will undoubtedly refine present methods of control. Basic information being gathered by nematologists will develop more efficient control measures. Screening of chemicals for control or eradication is being stepped up. As more effective and less expensive nematocides are developed, together with more efficient methods of applying them, the use of chemicals for nematode control will undoubtedly increase.

HISTORY AND ORIGIN OF THE GOLDEN NEMATODE

During Germany's campaign against sugarbeet nematodes in 1881, Julius Kuhn observed a cyst-forming nematode attacking potatoes. He recorded it as a curiosity—a possible subrace of *Heterodera schachtii* (*48*).[1]

That the nematode was actually a serious parasite of potatoes was not established, however, until 1913, when Massee (Scotland) and Zimmerman (Germany, 1914) proved Kuhn's "oddity" to be the real cause of what was then known as "soil sickness of potatoes" (*9*).

Within the following decade, the existence of the pest was discovered in England (1917), Sweden (1922), and Ireland (1922). Still thought to be a new species of *Heterodera schachtii*, the pest gained the common English name of "potato root eelworm" (*48*).

In 1923, however, Wollenweber observed that "potato larvae are slightly shorter than those of the sugarbeet nematode, and that their cysts are pear-shaped rather than lemon-shaped." Declaring that this was an entirely different species from that attacking sugarbeets, he proposed the name *Heterodera rostochiensis* since his specimens came from Rostock, Germany (*48*).

Despite Wollenweber's findings, scientific journals of the day continued to refer to the nematode as a race of the sugarbeet nematode (*15*). It was not until the excellent work of Franklin, years later, that *Heterodera rostochiensis* was given general recognition as a valid species.

The impact of the pest on the world's potato industry[2] has been spectacular since infested seed had been spread throughout much of the world long before *Heterodera rostochiensis* was named. Infestations have been discovered in such widely separated nations as Peru (1952), Iceland (1943), India (1961), and Panama (1967).

[1] Italic numbers in parentheses refer to Literature Cited, p. 77.

[2] For information on world potato production, see Appendix I.

Origin

For many years it was thought that the golden nematode originated in Europe. Some workers suggested that the nematode's sudden appearance was by mutation from a species of *Heterodera*, originally a parasite of some European garden weeds or ornamentals. Some advanced the theory that it was transported from an isolated area where the species may have lived on a sporadically occurring *Solanacaea*.

On April 3, 1951, a ship from Peru arrived at the port of Seattle, Wash. Plant quarantine inspectors of the USDA making routine inspection of the ship for plant pests collected soil from potatoes in the ship's stores and found the golden nematode. On September 25, 1951, a ship from Peru in the New York harbor was inspected and golden nematode cysts were found in the ship's stores in two different collections. These specimens were examined by USDA nematologists and were confirmed as being *Heterodera rostochiensis*. Since this pest had not been previously reported in Peru, a careful check was made of the ship's log to determine if the ship had taken on stores in other ports. All evidence pointed to the fact that the contaminated potatoes had originated in Peru.

A. L. Taylor of the Nematology Section, Crops Research Division, ARS, wrote to C. Bazan de Segura, Centro Nacional de Investigacion y Experimentacion Agricola de la Molina, Peru, advising of the finding of the golden nematode on ships from Peru and suggesting that a search be made in the country for the presence of the pest. As a result of this communication the nematode was found in February 1952 on potatoes from Tarma. A scientist from ARS, who was in Peru at the time the discovery was made, brought specimens back to Mr. Taylor in May 1952. Mr. Taylor confirmed identification as *Heterodera rostochiensis*.

The first account of this discovery was published in 1952 (*36*). The author, C. Bazan de Segura, stated that it was her opinion the *Heterodera rostochiensis* is indigenous to the

Andes. Later investigations conducted by Peruvian scientists determined that the nematode was widely distributed and was of an ancient origin.

Later, the nematode was discovered in the highlands of Bolivia and Argentina, where it is believed to be indigenous also.

The theory basing *Heterodera rostochiensis* origin in Peru is accepted by most nematologists today. Also, most botanists agree that the potato originated in Peru. Thus, one might logically ask why the golden nematode did not become a problem to European potato growers much earlier.

Potato tubers from South America had been well-distributed in Europe by early 1600. No doubt cysts of *Heterodera rostochiensis* were also distributed with these tubers, but under primitive cultural methods buildup was slow. By 1700 the potato had become a vital part of the basic food supply in Ireland, Scotland, Germany, and other western European countries.

However, little was done by agricultural scientists to improve the potato. Their interest was generally for its botanical characteristics. These earlier horticulturists did not seriously influence potato production or improvement of the few varieties that existed during this period. There was no serious attempt to develop new potato varieties until after the crisis in Ireland caused by late blight (1845). The potato famine that resulted gave the necessary stimulus to a new era of potato breeding, which led to commercial potato production.

From the mid-1800's to the end of that century there were revolutionary changes in potato growing. Plant breeders for the first time were guided by scientific principles of heredity and immunity in crop improvement. Between 1856 and 1876, large numbers of distinct varieties were produced and consumption of the potato in the people's everyday diet increased. It was probably during this period of intensified growing of potatoes and the distribution of seed for the establishment of commercial potato production that *Heterodera rostochiensis* was able to gain a foothold in Europe's potato fields.

Discovery in the United States

A farmer near Hicksville, Long Island, N.Y., was little concerned in 1934 when he noticed a few isolated spots in his potato field where vines were stunted and off color. Within 4 years, however, the spots had multiplied and commercial losses to his potato crop were being sustained. The farmer made repeated requests to his county farm bureau agent for

FIGURE 1.—Mature females attached to the roots become golden in color, hence the popular name "golden nematode" in the United States.

soil analysis or other explanation of his crop injury (*5*).

In July of 1941, Orson S. Cannon, a graduate student of the Department of Plant Pathology, Cornell University, attached to the Nassau County Farm Bureau, Long Island, visited the potato field and observed that the stunted and off-color appearance of the potatoes was similar to spots in sugarbeet fields infested with *Heterodera schachtii,* with which he was familiar (*4*). Cannon examined potato roots from the field and found numerous swollen female nematodes on the roots. Suspecting that this was the causative organism, he took specimens to the USDA Bulb Laboratory in Babylon, Long Island, where B. G. Chitwood, USDA nematologist, identified the specimens as *Heterodera rostochiensis* (*28*). Subsequent examination of the property showed that the entire field was infested and crop losses were as high as 70 percent; in an adjoining field, marked injury was apparent (*11*).

Available information on the distribution of the pest indicates that all Long Island infestations may have originated from this 40-acre field. The reuse of burlap bags for picking potatoes and the movement of farm machinery by renters were major factors in the local spread of the disease. More than 30 additional fields farmed by the operator of the original infested field have since been found infested. How and when the nematode gained entrance into the United States is not known. However, it could have been brought on military equipment being returned to Long Island military camps after World War I. From the extent of the infestation in 1941 and the history of the field, the nematode had probably been present for 20 years before it was identified (*13*).

H. rostochiensis is usually called the potato root eelworm in most European countries. However, to avoid confusion with other potato nematodes in the United States, Chitwood gave the pest its popular name of "golden nematode" (*7*) because the flask-shaped immature females attached to the roots become golden in color about the time the plants begin to bloom (fig. 1).

THE GENUS *HETERODERA*[3]

The golden nematode (*Heterodera rostochiensis* Wollenweber, 1923) (*51*) belongs in the "rostochiensis group" of the genus *Heterodera* Schmidt, 1871 (*35*). This group is typified particularly by the globular to ovate shape of the white females and cysts, and the character of the cyst wall pattern (fig. 2). Specific identification is based primarily on vulva-anal size and relationship, and to some extent, on morphological characters of the females and males, if these are available (fig. 3).

When *H. rostochiensis* nematode was first discovered in this country about 25 years ago, there was in the group only one other known and described species, *H. punctata* Thorne, 1928 (*46*). Since then several very closely related species have been found, and their accurate identification requires the efforts of someone thoroughly familiar with all the species.

In 1953, Cobb and Taylor (*16*) described *H. leptonepia* found in potatoes obtained from a ship's stores at Callao, Peru. This form is distinctive especially because of the strikingly slender larvae. Shortly after that, another species, *H. tabacum* Lownsbery and Lownsbery, 1954 (*25*), from tobacco in Connecticut was described. In 1959, a *Heterodera,* still undescribed and intermediate between *H. rostochiensis* and *H. tabacum* was found on horsenettle, *Solanum carolinense,* in Virginia; it is known to occur in other areas also. In 1961, another *Heterodera* in the *rostochiensis* group was found on tobacco in Virginia. These forms have been referred to, respectively, as the "horsenettle-cyst nematode" and the "Osborne cyst nematode" (*29*). The latter is closely related, and possibly identical, to *H. tabacum.*

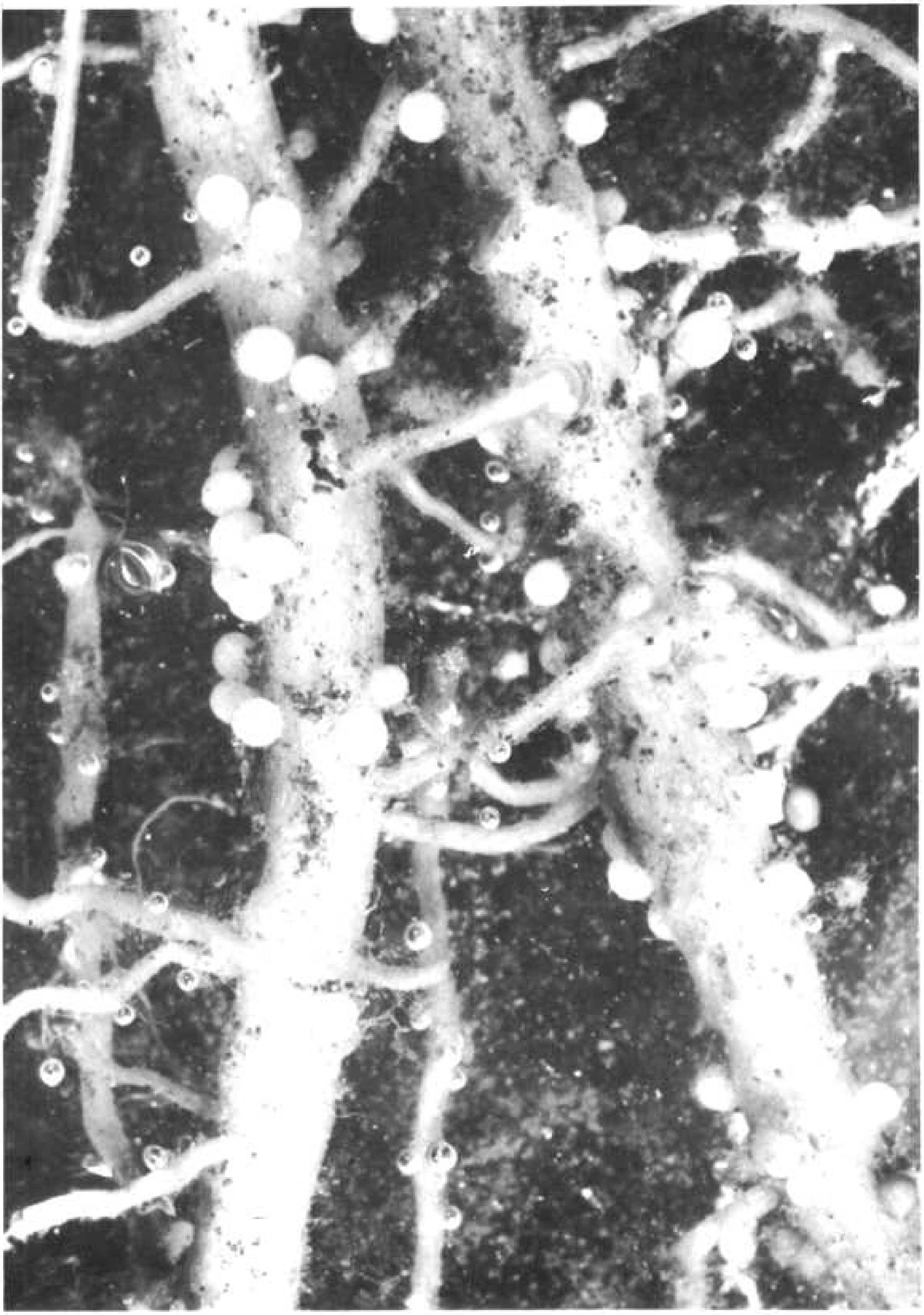
Knowing of the above closely related nematodes and keeping in mind the very probable existence of still undiscovered new species in the "rostochiensis group," one should be very cautious and thorough before concluding that any globular cysts that might be associated with potatoes are actually the golden nematode.

Key to the Mature Cysts of the More Common Species of *Heterodera*[4]

This key is designed to facilitate identification of the more common species of *Heterodera* that might be encountered in soil samples collected during a survey. Only characters of the mature cysts and their contents—that is, eggs with second stage larvae—are used. Certain characters used in the key may not be visible on other than fully mature cysts.

[3] Prepared by M. Golden, nematologist, Crops Research Division, ARS.

[4] Prepared by A. L. Taylor, nematologist, Crops Research Division, ARS. (Retired in 1967.)



BN 271

FIGURE 2.—Numerous immature swollen females on the roots of a potato plant.

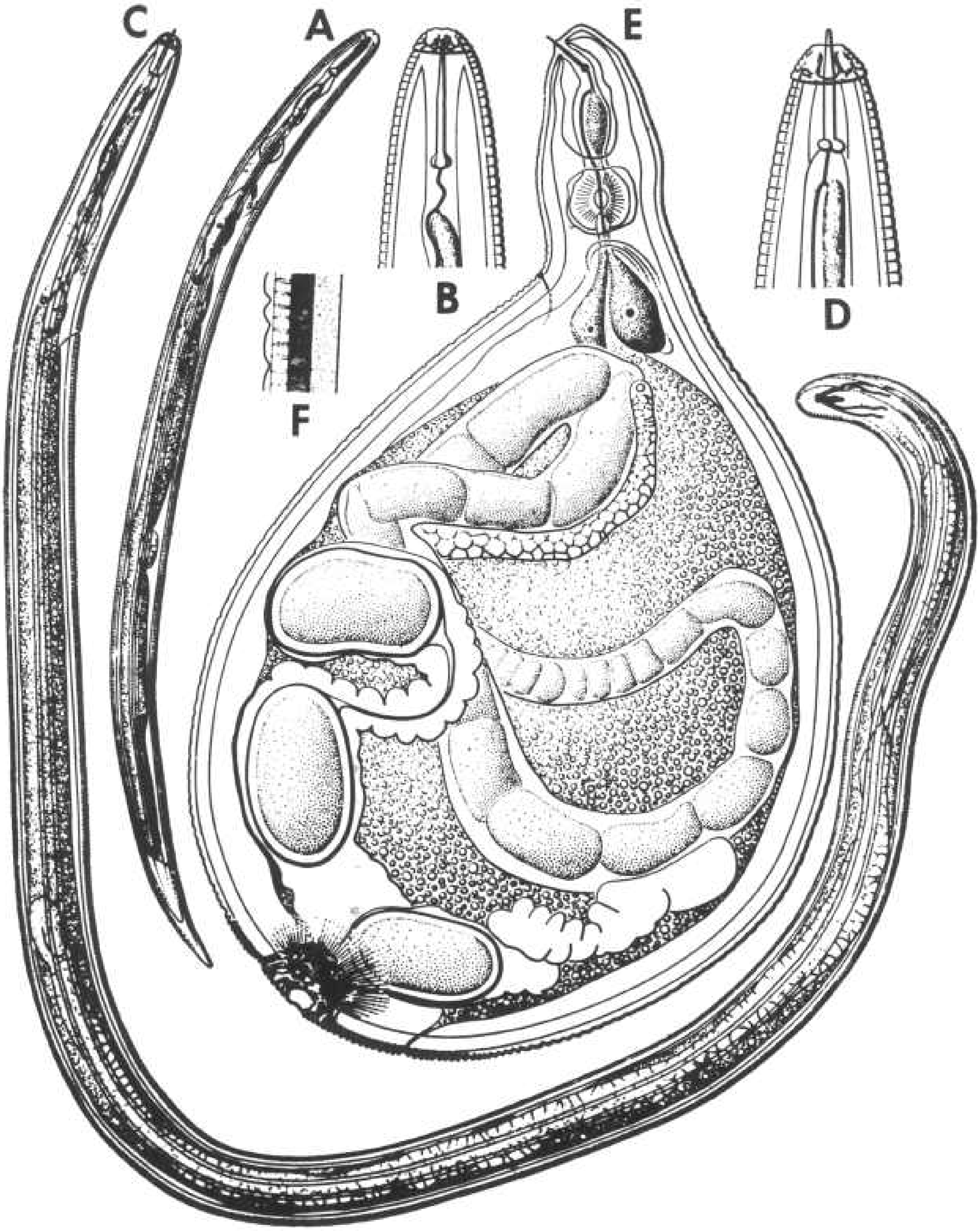


FIGURE 3.—The golden nematode of potatoes, *Heterodera rostochiensis* Wollenweber, 1923: (A) Infective larva, hatched from egg; (B) head of infective larva: (C) adult male; (D) head of adult male; (E) young adult female; (F) section of cyst wall (7).

Measurements of larvae are from Fenwick and Franklin (*18*) for most species, from Jones (*22*) for *H. carotae*, from Ichinohe (*21*) for *H. glycines*, and from Kirjanova (*23*) for *H. fici*.

1. Body of cyst, ovoid to globular, that is, with posterior portion rounded and vulva not located on a distinct protuberance ---------------------------- *Heterodera rostochiensis* group 4
   Body of cyst, lemon-shaped, that is, with vulva located on a distinct protuberance ---------------------------- 2
2. Basic element of pattern of outer layer of cyst wall at middle portion of cyst, short zigzag lines with little or no trace of regular transverse arrangement; sometimes modified to appear as network ---------------------------- 3
   Basic element of pattern at outer layer of cyst wall at middle portion of cyst, straight or wavy lines at right angles to axis of cyst; sometimes broken by short oblique or vertical lines; outer layer of cyst may have grainy appearance -------*Heterodera cacti* group 7
3. Mature cysts with dark bodies (brown knobs) and often sheaf-shaped object (lining of vagina) at posterior end. On immature cysts, these are seldom visible, and then do not appear dark ----- *Heterodera schachtii* group 8
   Mature cysts without brown knobs or sheaf-shaped object at posterior end -- *Heterodera gottingiana* group 11
4. *H. rostochiensis* group. Cyst often ovoid, anus located at a transparent spot on cyst so that anal and vulvar openings appear to be about the same size when seen by transmitted light. Hyaline portion of larval tail much longer than stylet -----------*Heterodera punctata*
   Cyst ovoid to globular; anal opening appears much smaller than vulva opening. Hyaline portion of larval tail about the same length as stylet --------------5
5. Larvae very slender; length about 39 times greatest width; orifice of dorsal oesophageal gland about two-thirds stylet length posterior to stylet knobs - *Heterodera leptonepia.*
   Length of larvae about 22 times greatest width; orifice of dorsal oesophageal gland about one-fourth stylet length posterior to stylet ------------------6
6. Distance between vulva and anus about two and one-half times diameter of vulva -------*Heterodera rostochiensis*
   Distance between anus and vulva about one and one-half times diameter of vulva -----------*Heterodera tabacum*
7. *H. cacti* group. Hyaline portion of larval tail about as long as stylet; stylet knobs concave anteriorly --*Heterodera weissi*
   Hyaline portion of larval tail usually shorter than stylet; stylet knobs convex anteriorly ---------*Heterodera cacti*
8. *H. schachtii* group. Cysts always with distinct, coarse punctation consisting of dots of uniform size but not in rows; brown knobs closely clustered around vulva. Hyaline portion of larval tail at least one and one half times longer than stylet ------------*Heterodera avenae*
   Cyst with or without punctation, fine and mostly in rows; brown knobs not closely clustered around vulva. Hyaline portion of larval tail about as long as stylet --9
9. Average length of larvae:
   480 microns ----------------------10
   about 460 microns *Heterodera schachtii*
10. Average length of larvae:
    484 microns ------*Heterodera glycines*
    502 microns -------*Heterodera trifolii*
    518 microns ---------------------- *Heterodera schachtii galeopsidis.*
11. *H. gottingiana* group.
    Average length of larvae:
    414 microns ---*Heterodera cruciferae*
    454 microns ------*Heterodera carotae*
    474 microns --*Heterodera gottingiana*
    405 microns ------*Heterodera humuli*
    406 microns ------- *Heterodera fici*

Type Host Plants [5]

Many lists of host plants of *Heterodera* species have been published, but it seems probable that many of these are inaccurate in that they include plants that are not hosts of the species discussed. This is true especially of the older lists and of those based on information compiled from the literature rather than from host tests. To avoid this particular error, the following list of host plants includes only the type host of each species and an indication of the other plants that it attacks, so far as there is general agreement or information on host tests available. That is, the list is not intended to be complete, but I believe it is accurate so far as what is included is concerned.

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[5] Prepared by A. L. Taylor, nematologist, Crops Research Division, ARS. (Retired in 1967).

The species of *Heterodera* and their principal hosts are as follows:

H. schachtii. Type host, sugarbeet (*Beta vulgaris* L). Also other Chenopodiaceae, many species of Cruciferae and various species of other plant families (*47*). It seems possible that *H. schachtii* attacks a wider variety of plants than any other known species of *Heterodera.*

H. gottingiana. Type host, garden peas (*Pisum sativum* L.) and other Leguminosae. But according to Oostenbrink (*31*), this species does not attack beans (*Phaseolus vulgaris* L.), clover (*Trifolium* spp.), alfalfa (*Medicago sativa* L.), or soybeans (*Soya max* Piper).

H. trifollii. Type host, red clover (*Trifolium pratense* L.) and other Leguminosae, including beans (*Phaseolus vulgaris* L.) but not peas (*Pisum sativum* L.) alfalfa, or soybeans.

H. glycines. Type host, soybean (*Glycine max* L.) and snap bean (*Phaseolus vulgaris* L.), Adzuki bean (*P. angularis*), vetch (*Vicia* sp.), annual lespedeza (*Lespedeza stipulacea* Maxim.), henbit (*Lamium* sp.).

H. major. Type host, oats (*Avena sativa* L.) and other Gramineae.

H. cruciferae. Type host, cabbage (*Brassica oleracea* L.) and other Cruciferae.

H. carotae. Type host, carrot (*Daucus carotae* L.). Wild carrot (*Daucus carotae*) is the only other known host (*22*).

H. humuli. Type host, hops (*Humulus lupulus* L.) and other Urticaceae.

H. galeopsidis. Type host, hemp nettle (*Galeopsis tetrahit* L.). Also other Labiatae and some species of Chenopodiaceae and Carophyllaceae (*22*).

H. fici. Type host, rubber plant (*Ficus* sp.).

H. weissi. Type host, knotweed (*Polygonum pensylvanicum* L.). No other hosts known.

H. cacti. Type host, Phyllocactus (*Epiphyllum ackermanni*) and other Cactaceae.

H. rostochiensis. Type host, potato (*Solanum tuberosum* L.). Also tomato (*Lycopersicon esculentum* Mill.) and a few other species of Solanaceae (*30*) but not tobacco (*Nicotiana tabacum* L.) (*45*).

H. tabacum. Type host, tobacco (*Nicotiana tabacum* L.) and tomato.

H. punctata. Type host, wheat (*Triticum vulgare* Vill.) and other Gramineae.

BIOLOGY

Life History

The golden nematode passes through the egg, larval, and adult stages in its development. From 38 to 48 days are required for the egg-to-adult cycle (*9*).

The eggs hatch within the dead, swollen bodies of fertilized females, which are called cysts. Cysts are flask shaped and are much smaller than a pinhead. Each cyst may contain up to 500 eggs. The cyst is a protective covering for the eggs and is resistant to chemicals, to drying, and to some soil organisms (fig. 4).

In the spring when the soil temperature is around 60° F. a chemical given off by potato or tomato roots stimulates larvae to hatch from the eggs, leave the cyst through an opening in the wall, and migrate to host plants. Larvae enter the roots where they feed. At temperatures below 55° F. there is little activity of the larvae (*10*).

In the roots, golden nematodes take up a position near the plant's vascular system and then undergo a series of changes. The females become stationary; they swell and break through the roots, to which they remain attached by a thin neck. The males retain their slender eellike form and mate with the females. After fertilization, several hundred eggs develop within the female whereupon the female dies.

The golden nematode cyst is visible to the unaided eye. At first, it is pearly white. Later, it turns golden, orange, and finally brown. Cysts become detached from the roots and remain in the soil after the crops have been harvested (*40*) (fig. 5).

BN 30081

FIGURE 4.—Golden nematode females washed from potato soil. Each cyst may contain up to 500 eggs.

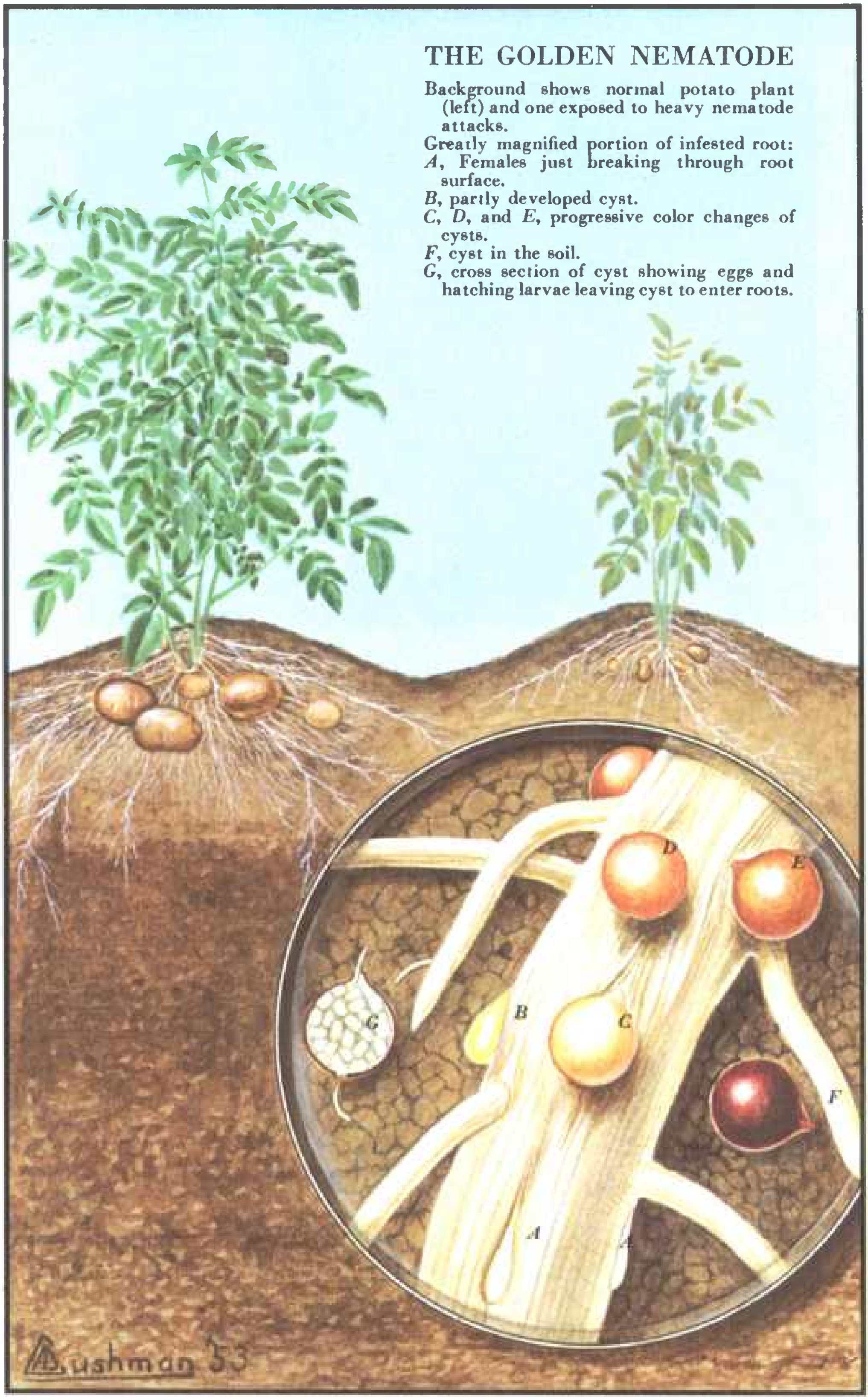

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FIGURE 5

BN 30006

FIGURE 6.—Aboveground symptoms of golden nematode damage.

Symptoms of Infestation

Soil populations of the golden nematode sufficiently high to cause plant damage are produced only after buildup on several potato crops. At first there is no aboveground evidence of plant damage. This lack of distinguishable symptom of the early stages is an aid to the organism. After host crops have been repeatedly grown on infested land, then distinct aboveground signs of damage begin to appear (*40*) (fig. 6).

The first sign is poor growth of plants in small spots in the field. These spots are similar to that of plants in low spots in wet years and high spots during dry years. No one plant symptom alone can be relied upon as evidence of the disease. If the infestation grows, the spots become larger and additional spots appear (*27*).

Aboveground symptoms appear only in the presence of large numbers of nematodes in the soil. Heavy infestations cause considerable wilting of plants, especially during midday, stunting of growth, poor root development, and poor plant growth. Before enough nematodes develop in the soil to cause aboveground symptoms, immature females may be seen on the roots. By carefully removing the plants and roots at blossom time, the white, yellow, or golden flask-shaped females attached to the root may be seen with the unaided eye (*40*).

Populations of the golden nematode on Long Island are so low that aboveground symptoms seldom occur except in the experimental area of the golden nematode laboratory. In this area symptoms of heavily infested plants are generally evident the latter part of May and early June. Extensive soil surveys detect infestations as soon as they reach the discovery level.

The effect of the golden nematode on tomatoes is similar to that on potatoes. Growth of plants is retarded and wilting is particularly noticeable (fig. 7). Leaves of heavily infested plants are purplish, instead of yellowing as in potatoes, and the lower leaves may die (*38, p. 178*).

The nematode in the early stages of the attack on tomatoes causes slight swelling of the roots, which may be confused with galling caused by the root-knot nematode (*38, p 178*).

Host Plants

The only commercial crops known to be attacked by the golden nematode are *Solanum tuberosum* (potatoes), *Lycopersicon esculentum* (tomatoes), and *S. melongena* (eggplant) (*27*).

BN 29988

FIGURE 7.—*(Left)* Healthy tomato plants. *(Right)* Tomato plants stunted by the golden nematode.

Among other plants that may also become infected, thereby helping to propagate this pest, are *Solanum dulcamara* (bitter nightshade), *S. rostratum* (buffalo bur), *S. triflorum* (cutleaf nightshade), *S. elaeagnifolium* (silverleaf nightshade), *S. blodgettii, S. xanti* (purple nightshade), and *S. integrifolium* (tomato eggplant) (*15*).

Plant breeders have found about 90 species of the *Solanum* to be host of the golden nematode. Although most of these plants are wild species not occurring in the United States, most do occur in South America (*38 p. 176*).

Rate of Population Increase

Damage by the golden nematode to host crops is caused by mass invasion on the roots by nematodes that kill or damage the root system, depriving the plant of the necessary food.

The relative increase in the number of nematodes in the soil from the growing of a potato crop is greatest when the number of nematodes is low (*27*). This is because the plant is able to produce a vigorous root system, and the nematodes have an abundant root system on which to feed. The nematodes attacking the root are less concentrated, and thus few roots are killed. However, as the number of nematodes increases in the soil, the annual increase of nematodes from the continual growing of potatoes is less because more roots are killed and both the plant and the nematodes are deprived of an adequate food supply.

When the concentration of nematodes reaches a level to cause total failure of the potato crop, the number of living nematodes in the soil drops substantially (*27*). This, of course, is due chiefly to the lack of food to sustain the population. The following year it may be possible to grow a fair potato crop because enough nematodes have died so the plant can produce a root system to sustain itself. At these high degrees of infestation, the crop will always be irregular and always be poor.

In the absence of host crops, the rate of decrease in viable cysts may be as much as 50 to 80 percent the first year; however, the rate of decrease continues at a smaller rate with some viable cysts remaining for many years. Grainger (*19*) of the West Scotland Agricultural College reported that the golden nematode wastes away at a fairly standard percent annually in the absence of host plants, because of normal aging and ultimate death of the nematode and attack by other organisms.

Normal aging appears to be logarithmically dependent on temperature, being greater in warm climates than in cooler climates. Infestations of the golden nematode never assume very serious proportions in warm countries, where natural wastage is so high that even relatively short crop rotations would reduce populations to very low levels and longer rotations would eliminate them entirely. In cool areas, like Scotland, however, the annual wastage could be as low as 18 percent. Grainger also says that a moderate infestation of nematodes, still in a viable state, could be expected to cause serious disease "up to 30 years after the last potato crop." This expectation, according to Grainger, has been confirmed by careful checking of actual instances, which involved persistence of 27 to 28 years (*19*).

United States Department of Agriculture research workers Chitwood and Feldmesser (*14*) found the increase on one potato crop on Long Island to be about tenfold to twentyfold until approximately 50,000 cysts per plant were

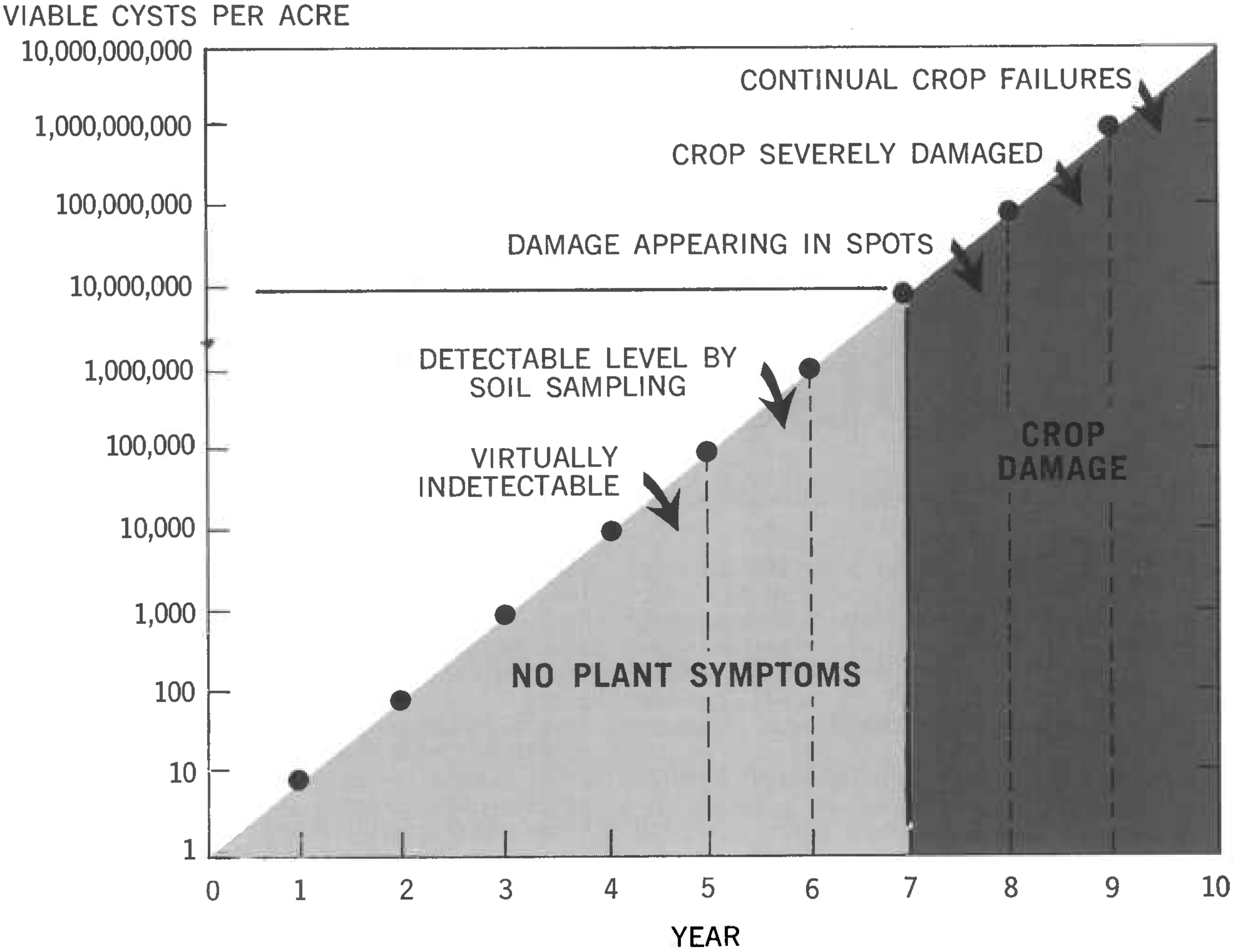


FIGURE 8.—Increase in golden nematode populations in a continuous potato culture, assuming a tenfold increase.

formed. Research workers in the Netherlands have, in general, agreed with USDA findings. In the Government-enforced rotation program, the Netherlands has assumed, for practical purposes, a tenfold increase of the nematode on a crop of potatoes and a decrease of 50 percent in the absence of a potato crop.

Figure 8 shows graphically an increase of golden nematode infestation in a continuous potato culture assuming a tenfold increase (*44*).

THE POTATO AND TOMATO INDUSTRIES

The economic potential of the golden nematode, if left uncontrolled, can have serious effects on the potato industry. Potatoes are a major food crop in many countries.

Potato production in 1966 in the principal producing countries, estimated at 5,100 million hundredweight (100 lb.), was 1 percent above the 1965 crop but 2 percent below the 1960–64 average. Total acreage, estimated at 44 million acres, continued its gradual downward trend, whereas yields in general increased. Higher yields more than offset the effect of decreased acreage.

Tomatoes are not as widely grown as potatoes; however, they are an important crop for both the fresh market and for processing. Tomato production in 1965 in the principal producing countries of the world is estimated at 420 million hundredweight produced on about 2.5 million acres.

Europe leads the world in tomato production, followed by North America, the Near East, Latin America, the Far East, Africa, and Oceania. The 10 leading tomato-producing countries are United States, Italy, Spain,

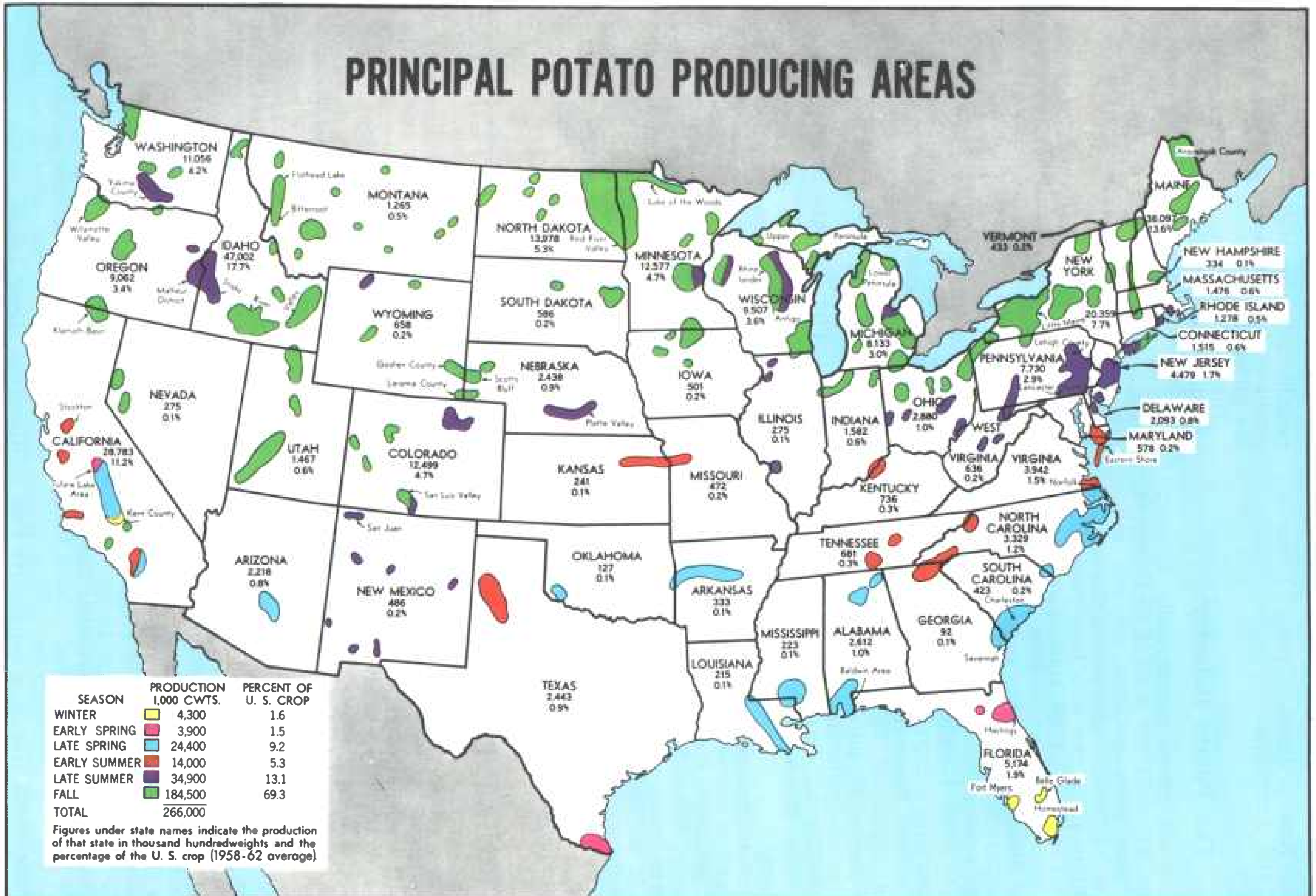

PRINCIPAL POTATO PRODUCING AREAS
WASHINGTON 11,056 4.2%
OREGON 9,062 3.4%
IDAHO 47,002 17.7%
MONTANA 1,265 0.5%
NORTH DAKOTA 13,878 5.3%
Red River Valley
MINNESOTA 12,577 4.7%
WISCONSIN 9,507 3.6%
MICHIGAN 8,133 3.0%
MAINE 36,097 13.6%
Aroostook County
VERMONT 433 0.2%
NEW YORK 20,359 7.7%
NEW HAMPSHIRE 334 0.1%
MASSACHUSETTS 1,476 0.6%
RHODE ISLAND 1,278 0.5%
CONNECTICUT 1,515 0.6%
NEW JERSEY 4,479 1.7%
PENNSYLVANIA 7,730 2.9%
DELAWARE 2,093 0.8%
MARYLAND 578 0.2%
Eastern Shore
WYOMING 658 0.2%
SOUTH DAKOTA 586 0.2%
NEBRASKA 2,438 0.9%
Platte Valley
IOWA 501 0.2%
ILLINOIS 275 0.1%
INDIANA 1,582 0.6%
OHIO 2,880 1.0%
WEST VIRGINIA 636 0.2%
VIRGINIA 3,942 1.5%
Norfolk
NEVADA 275 0.1%
UTAH 1,467 0.6%
COLORADO 12,499 4.7%
San Luis Valley
KANSAS 241 0.1%
MISSOURI 472 0.2%
KENTUCKY 736 0.3%
CALIFORNIA 28,783 11.2%
Stockton
Tulare Lake Area
Kern County
Klamath Basin
ARIZONA 2,218 0.8%
NEW MEXICO 486 0.2%
San Juan
OKLAHOMA 127 0.1%
ARKANSAS 333 0.1%
TENNESSEE 681 0.3%
NORTH CAROLINA 3,329 1.2%
SOUTH CAROLINA 423 0.2%
Charleston
GEORGIA 92 0.1%
Savannah
TEXAS 2,443 0.9%
LOUISIANA 215 0.1%
MISSISSIPPI 223 0.1%
ALABAMA 2,612 1.0%
Baldwin Area
FLORIDA 5,174 1.9%
Hastings
Belle Glade
Fort Myers
Homestead
SEASON | PRODUCTION 1,000 CWTS. | PERCENT OF U. S. CROP
WINTER 4,300 1.6
EARLY SPRING 3,900 1.5
LATE SPRING 24,400 9.2
EARLY SUMMER 14,000 5.3
LATE SUMMER 34,900 13.1
FALL 184,500 69.3
TOTAL 266,000
Figures under state names indicate the production of that state in thousand hundredweights and the percentage of the U. S. crop (1958-62 average)

FIGURE 9

Bulgaria, Brazil, Japan, Greece, Rumania, Mexico, and Argentina.

The Potato Industry

Potatoes are grown commercially in every State (fig. 9), and there is not a single month in the year when potatoes are not being planted or harvested somewhere in the country (*49*). Potato yields per acre have risen from a national average of 80 hundredweight per acre in 1940 to 210 cwt. in 1966. It has been predicted that the national average per-acre yield may rise to as much as 250 cwt. by 1975. The total acreage decreased from 2.8 million in 1940 to about 1.5 million in 1966.

Potatoes have a market value of about $600 to $800 million. When transportation, packaging, and marketing facilities are included, potatoes are a $3 billion industry. The 10 leading potato-producing States are Idaho, Maine, California, New York, Washington, North Dakota, Minnesota, Wisconsin, Colorado, and Oregon.

As a potato-producing area, Suffolk County, Long Island, is outranked in the United States only by Aroostook County, Maine, and Bingham County, Idaho. The potato acreage on the Island was rapidly expanded during World War II. It may have been during this expansion that the golden nematode spread from the original field in Nassau County to eastern Suffolk County—a distance of over 100 miles. Potato production on Long Island reached its peak in 1946, when well over 62,000 acres were produced. It decreased to about 40,000 acres in the midsixties.

The yield per acre, which rose rapidly during and following World War II, continues to increase but at a slower rate. In recent years, yields have averaged 250 to 260 cwt. per acre. Of this yield, about 235 to 240 cwt. may be sold; the rest is offgrade or used for home consumption.

Hicksville—once the center of potato production in Nassau County—is now the center of a large suburban area of New York City. The population of Nassau County has grown from about 400,000 in 1941 to more than 1,400,000 in 1967. Almost all of the infested potato fields in Nassau County have become house lots or industrial sites. The golden nematode, however, continues to threaten the potato industry in Suffolk County.

The Tomato Industry

Tomatoes are widely grown in the United States for both processing and fresh market. Most of the tomato crop is field grown. About 275,000 acres of tomatoes are grown for processing; the crop value is about $160 million. Tomatoes for the fresh market are grown on 170,000 acres; the annual value is about $190 million.

The 10 leading tomato-producing States are California, Ohio, Florida, New Jersey, Indiana, Illinois, Pennsylvania, Maryland, Michigan, and New York.

CONTROL OF THE GOLDEN NEMATODE IN THE UNITED STATES

When the golden nematode was discovered on Long Island in 1941, Cornell University and the U.S. Department of Agriculture undertook a cooperative research program, and the New York State Department of Agriculture and Markets and the USDA conducted surveys. With the involvement of the United States in World War II, however, the amount of attention that could be devoted to the problem was limited.

By 1944, it had become obvious that the nematode was much more widespread on Long Island than it had been thought at first. In that year, the State invoked a quarantine (*33*), and the Bureau of Entomology and Plant Quarantine, USDA, began a survey in 19 potato-producing States east of the Mississippi River to see if the nematode had spread outside Long Island (*10*).

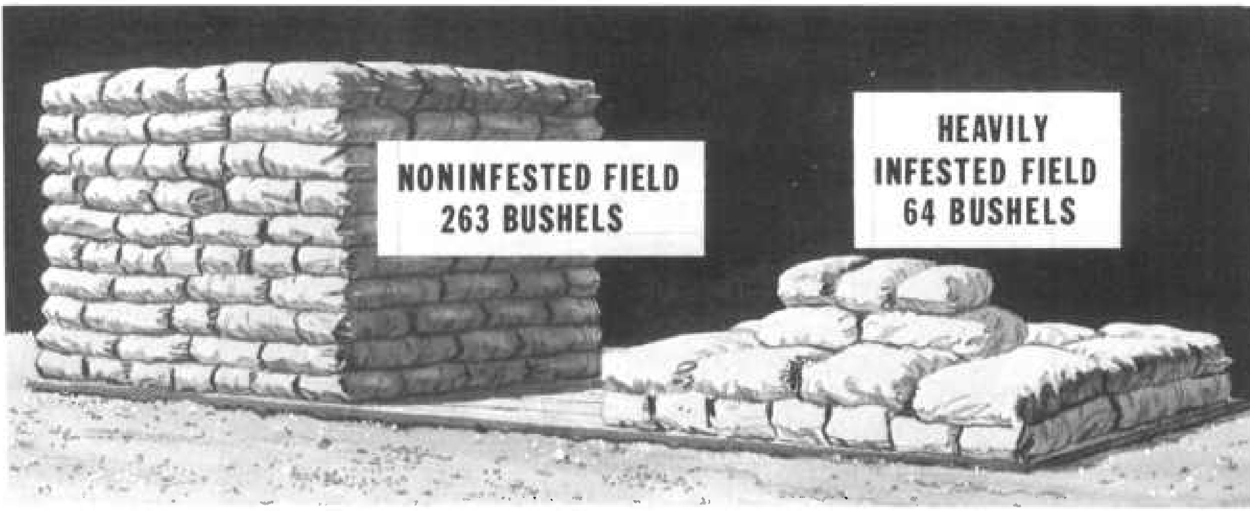
Following World War II, a cooperative Federal-State Golden Nematode Control Project was established. Research facilities were greatly expanded, and the staff to operate the program was also expanded. The program was divided into four main branches: Survey, laboratory processing of samples, quarantine enforcement, and research. Systematic soil surveys were begun of all fields on Long Island, and surveys were expanded to include all potato-producing areas of the United States (fig. 9). Quarantine regulations were strengthened.

The following offices and laboratories have been set up for the golden nematode program on Long Island:

(1) A headquarters building at Hicksville houses the program offices of both the USDA's Plant Pest Control Division and the New York State Department of Agriculture and Markets, a laboratory, and a storage garage.

(2) A work unit office is maintained at Riverhead, Long Island.

(3) New York State College of Agricul-



BN-28195

FIGURE 10.—Yields of Green Mountain potatoes per acre, based on a 5-year average.

ture, Cornell University, Department of Plant Pathology, maintains a laboratory and greenhouse facilities at Farmingdale. Approximately 8 acres of land is available here for field tests (fig. 10).

Research and Methods

The laboratory at Farmingdale investigates many phases of the golden nematode problem. But its primary concern involves (1) investigations into rotation and resistance, biotype buildup, race determination, and breeding of potato varieties resistant to the golden nematode, and (2) investigations into chemical control, which include screening of nematocides, evaluation of promising new nematocides, and determination of techniques and conditions for optimum nematocide effectiveness.

The Plant Pest Control Division's Methods Improvement Operations works closely with Cornell scientists in their research program. The Methods Improvement personnel develop and improve machinery for applying nematocides to the soil, ways of field-scale testing of candidate nematocides that show promise for use in a control program, and ways of field-scale testing of fumigants under tarpaulin seal; they also develop regulatory treatments to free of infestation nursery stock, farm machinery, burlap bags, and other commodities so that they may be safely moved.

Research has gone forward with very significant progress in various fields. A chemical treatment program and commercially acceptable varieties of potatoes resistant to the golden nematode have been the two most valuable findings in making a breakthrough in solving this pest problem.

Survey Results

During the first 10 years of the program the golden nematode seemed to be confined to western Long Island, mainly Nassau and western Suffolk Counties. The vast potato acreage of eastern Long Island remained free of the nematode until 1950, when several infested properties in Bridgehampton were found (fig. 11).

With establishment of systematic surveys in 1946, the number of properties known to be infested rose sharply. During the period 1946-52, the number of properties found infested averaged 34 annually, comprising 1,362 acres. Beginning in 1947 real estate interests bought up much of Nassau County's agricultural land for houses and by 1956 few potato fields remained. As farmland became scarce in Nassau County, builders began to purchase potato fields in western Suffolk County. During the period 1954-67, the average number of properties found infested each year dropped to 7, and the average acreage dropped to about 361 (fig. 12).

Since the golden nematode program began, 387 properties consisting of 17,151 acres, have been found infested (table 1 and fig. 12). Of this total about 11,413 acres of infested agricultural land have been permanently removed from agriculture for real estate development (table 2). Of the remaining infested acres, 4,389 have received soil treatment and have

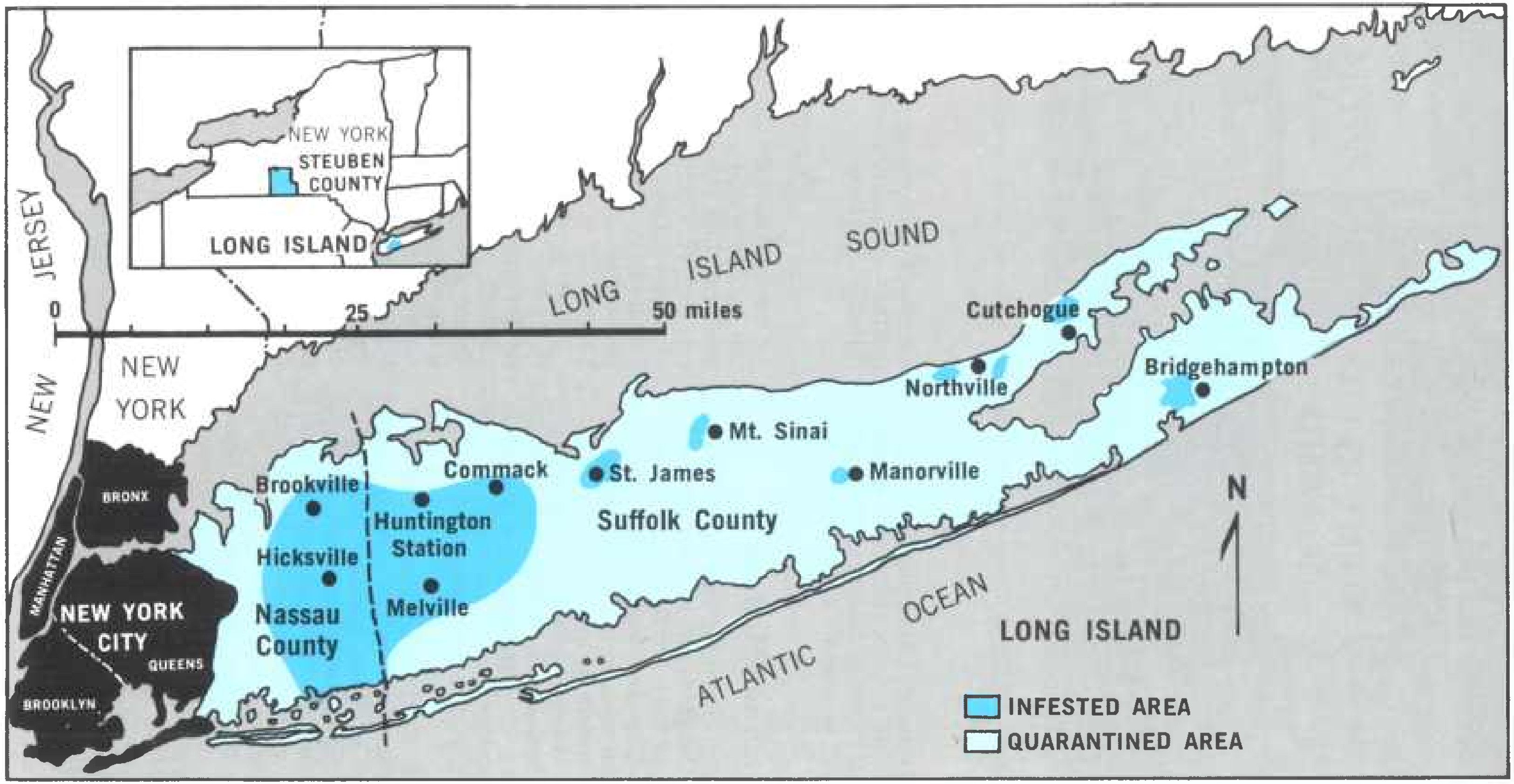

NEW YORK
STEUBEN
COUNTY
LONG ISLAND
JERSEY
NEW
NEW
YORK
0
25
50 miles
LONG
ISLAND
SOUND
Cutchogue
Bridgehampton
Northville
Mt. Sinai
St. James
Manorville
Commack
Brookville
Huntington
Station
Suffolk County
Hicksville
Melville
Nassau
County
BRONX
MANHATTAN
NEW YORK
CITY
QUEENS
BROOKLYN
OCEAN
ATLANTIC
LONG ISLAND
N
INFESTED AREA
QUARANTINED AREA

FIGURE 11

been released for agricultural use, thus leaving 1,350 acres of agricultural land to be treated.

The following tabulation shows the status on January 1, 1968, of the infested land remaining to be treated:

Land use	*Acres*
Vegetable crops	577.74
Potato land (Steuben County)	55.00
Cultivated sod	281.74
Pasture	108.87
Pending development (for real estate purposes)	326.67
Total	1,350.02

Early regulatory action and the strict enforcement of the State quarantine has played a large part in restraining the spread of the golden nematode. The withholding of potatoes and tomatoes from infested land has been the most important single thing done to control the spread. Fortunately, the infested fields had low nematode populations, and the fields were on an island.

However, administrators of the quarantine had recognized, before discovery of the golden nematode on Long Island or the enactment of strict quarantine regulations, that the pest could be transported to other potato-growing areas.

During the early 1940's a few Long Island farmers either moved to western New York or operated farms both in western New York and on Long Island. Because of the operational exposure of these farms, surveys are made annually in western New York.

On December 2, 1967, the golden nematode was found on a 55-acre field in Steuben County, N.Y., near the town of Prattsburg. The in-

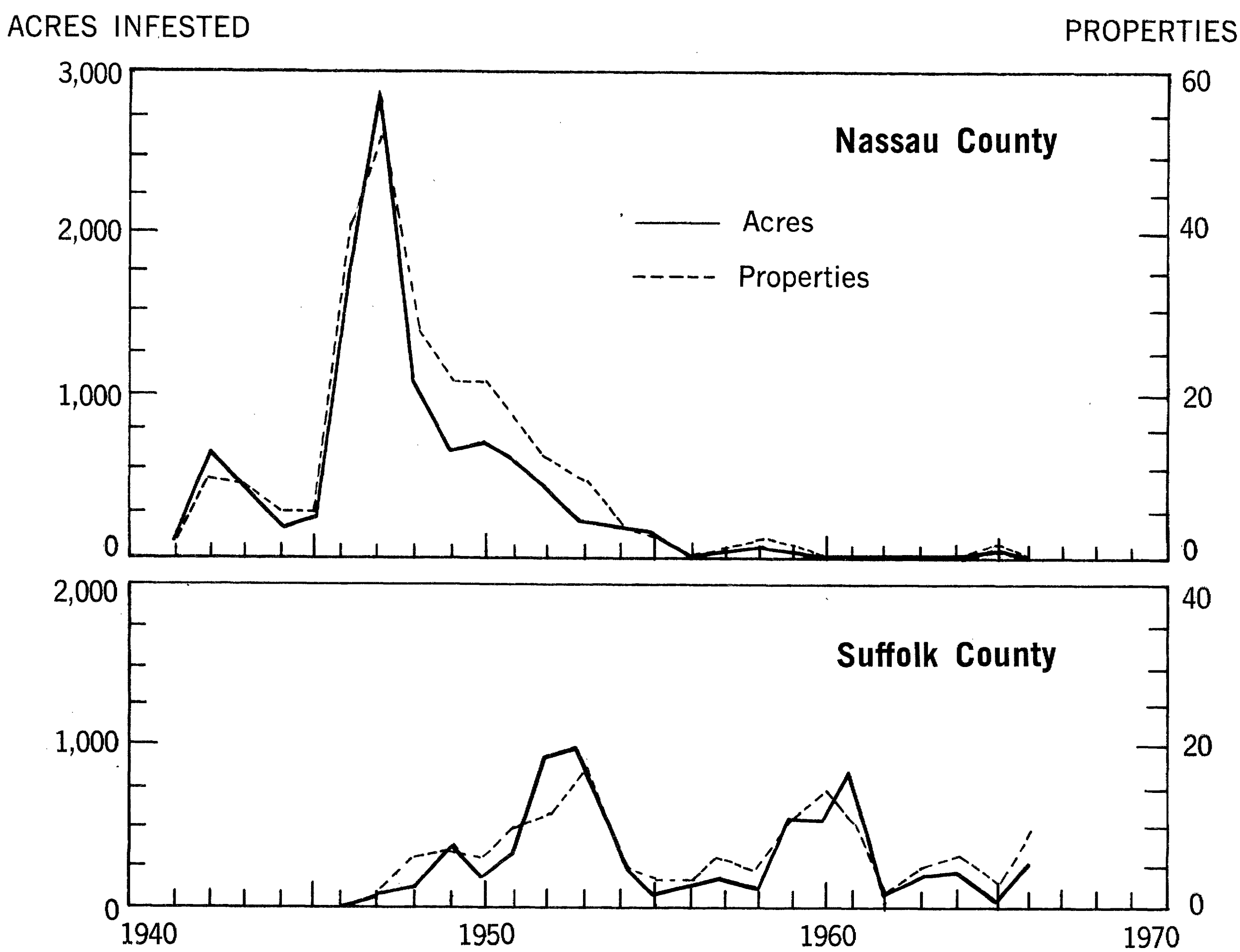


FIGURE 12.—Results of Long Island nematode survey. Number of properties and gross acreage infested, Nassau and Suffolk Counties, 1941–66.

TABLE 1.—*New infestation of golden nematode in Nassau, Suffolk, and Steuben Counties, by years, 1941–67*

Year	Nassau County		Suffolk County		Steuben County		Total properties	Gross acres [1]	Remarks
	Properties	Acreage infested	Properties	Acreage infested	Properties	Acreage infested			
1941	2	115.66	0	0	0	0	2	116	First discovered in U.S.
1942	9	541.86	0	0	0	0	9	542	Plant pulling or irregular pattern of soil sampling, 1941–45.
1943	8	437.36	0	0	0	0	8	437	
1944	5	142.98	0	0	0	0	5	143	
1945	5	165.88	0	0	0	0	5	166	
1946	41	1,656.50	0	0	0	0	41	1,656	Golden nematode project established—systematic soil sampling began.
1947	52	2,793.28	1	30.00	0	0	53	2,823	First Suffolk County.
1948	27	1,034.66	6	216.95	0	0	33	1,252	Commack, N.Y.
1949	22	663.00	7	350.15	0	0	29	1,013	
1950	22	660.56	6	232.88	0	0	28	893	Bridgehampton, N. Y.
1951	16	544.75	10	302.80	0	0	26	848	Cutchogue, N. Y.
1952	13	261.12	12	790.61	0	0	25	1,052	Mt. Sinai, N. Y.
1953	8	167.43	18	989.20	0	0	26	1,157	
1954	3	143.24	5	266.00	0	0	8	409	
1955	2	130.00	3	85.30	0	0	5	215	St. James, N. Y.
1956	0	0	3	153.00	0	0	3	153	None in Nassau County.
1957	1	7.92	7	263.70	0	0	8	272	
1958	2	181.00	4	322.94	0	0	6	504	
1959	1	72.00	11	629.75	0	0	12	702	
1960	0	0	14	629.39	0	0	14	629	
1961	0	0	10	827.63	0	0	10	828	
1962	0	0	2	113.00	0	0	2	113	
1963	0	0	6	304.95	0	0	6	305	
1964	0	0	7	339.62	0	0	7	340	
1965	1	30.00	4	116.85	0	0	5	147	Manorville, N. Y.
1966	0	0	10	382.36	0	0	10	382	
1967	0	0	0	-------	1	55	1	55	First infestation found off Long Island.
Total	240	9,749.20	146	7,347.08	1	55	387	17,151	

[1] Rounded to nearest acre.

TABLE 2.—*Infested land at beginning of each year, land found infested during year, land removed from agriculture by real estate development, land treated and released for potato production, and agricultural land remaining to be treated, Long Island, 1955–67*

Year	Infested land at beginning of each year	Land found infested during year	Land removed from agriculture by real estate development	Land treated and released for potato production	Agricultural land remaining to be treated
	Gross acres	*Gross acres*	*Gross acres*	*Gross acres*	*Gross acres*
1955	[1] 12,722.17	0	6,832.18	0	5,889.99
1956	12,722.17	153.00	796.96	10.00	5,236.03
1957	12,875.17	271.62	103.37	0	5,404.28
1958	13,146.79	503.94	0	10.61	5,897.61
1959	13,650.73	687.30	691.47	67.32	5,826.12
1960	14,338.03	643.84	876.57	656.31	4,951.53
1961	14,996.32	827.63	107.20	1,275.63	4,381.88
1962	15,809.50	113.00	624.17	783.11	3,087.60
1963	15,922.50	304.95	451.06	511.50	2,429.99
1964	16,227.45	339.62	517.45	360.04	1,892.12
1965	16,567.07	146.85	252.00	240.87	1,546.10
1966	16,713.92	382.36	29.00	429.14	1,470.32
1967	17,096.28	55.00	131.10	44.20	1,350.02
1968	[2] 17,151.28	------	------	------	------

[1] Cumulative figures for 1941–55. See table 1.
[2] Includes infestation found in Steuben Co., N. Y.

festation was detected by Plant Pest Control Division personnel who had conducted surveys in western New York potato-growing counties in October and November.

Survey Procedures

The undramatic nature of the pest in its early stages is an aid to its survival. It is very important that the organism be recognized before crop damage becomes apparent; therefore, it is necessary that a constant alert be maintained for its presence throughout the potato- and tomato-producing areas of the country. Small or isolated infestations may exist unnoticed, since plant symptoms are not reliable in the detection of the golden nematode. In the early stages, buildup of populations is slow, and crop damage may not be noticeable for several years.

The most reliable method for the detection of the golden nematode is the collection of soil samples and the microscopic examination of the washed residue. Yield losses are quite evident when the concentration of cysts reach approximately one billion per acre. However, the presence of the golden nematode may be detected before the concentration of the cysts in the soil reach the level where they will cause crop loss.

From the records of more than 100 fields of the many hundreds surveyed on Long Island, it has been determined that, with the survey procedures herein outlined, cysts of the golden nematode may be found on the average when the concentration is approximately one million per acre. Assuming 10 viable cysts were initially introduced into a field and there was a tenfold increase per year, it would take approximately 6 years for a cyst population to build up to the discovery level. Crop damage may not become apparent for another 3 years, during which time the cyst population may build up to a billion per acre (fig. 8).

From this evidence it can easily be understood that a large number of cysts may exist in a potato field in which no symptoms are noticeable on the tops or the tubers. For this reason nematodes may be found in a field that has been surveyed with negative results for several years. This is also the reason that surveys must be conducted continuously and systematically.

Survey Crew

Soil survey crews normally consist of three or four men, one of whom is designated as the crew leader. The number of men assigned to survey a given property or area will vary with the district in which they operate and the scope of such operations. One man can survey about 25 acres per day; therefore, the crew may be varied from one to several men, depending upon the size of fields to be surveyed (fig. 13).

Equipment

Each crew is provided with a map of the area to be surveyed, a supply of No. 12 wet-strength, fungusproof, double-wall paper bags, a felt marker or wax marking crayon, a long-handled (28-inch) pointing trowel for each member of the crew, wire staplers or tape for sealing the bags, a bristle brush for cleaning shoes and equipment, and forms on which to record field survey operations (fig. 14).

Field Soil Sampling

Upon arrival at the premises to be surveyed, the crew leader should look over the property and determine the boundaries, size, and shape of the field, and plan how the field will be surveyed. If the owner or operator has not been previously contacted, the crew leader should do so before beginning work.

It is advisable to divide the field into several small subdivisions or working units. With such subdivisions, it will be possible to return to a given unit to pinpoint an infestation should cysts be found in the sample. They also permit a systematic survey of the field and give the laboratory soil samples of proper size for processing.

In the initial survey, the field is divided into working units of approximately three-fourths to one acre each. The survey is usually conducted in a grid pattern; about a tablespoon of soil is collected on the end of the trowel about every eight paces. This procedure is

BN-29989

FIGURE 13.—Survey crew collecting soil samples.

commonly referred to as the 8 × 8 block method. By this method, one composite sample weighing 4 to 6 pounds will be collected from every three-fourths to one acre of soil inspected.

If a more intensive survey is desired, soil is collected on a 4 × 4 pace interval. By this system, four times the volume of soil will be collected as by the 8 × 8 pace method.

For a still more intensive survey, soil may be collected on a 2 × 2 pace interval. By this procedure, 16 times the volume of soil will be collected as by the 8 × 8 pace method. The 4 × 4 and 2 × 2 pace methods of survey are generally used for pinpointing an infestation following the initial discovery by the 8 × 8 pace method or for collecting samples for viability purposes following field soil fumigation.

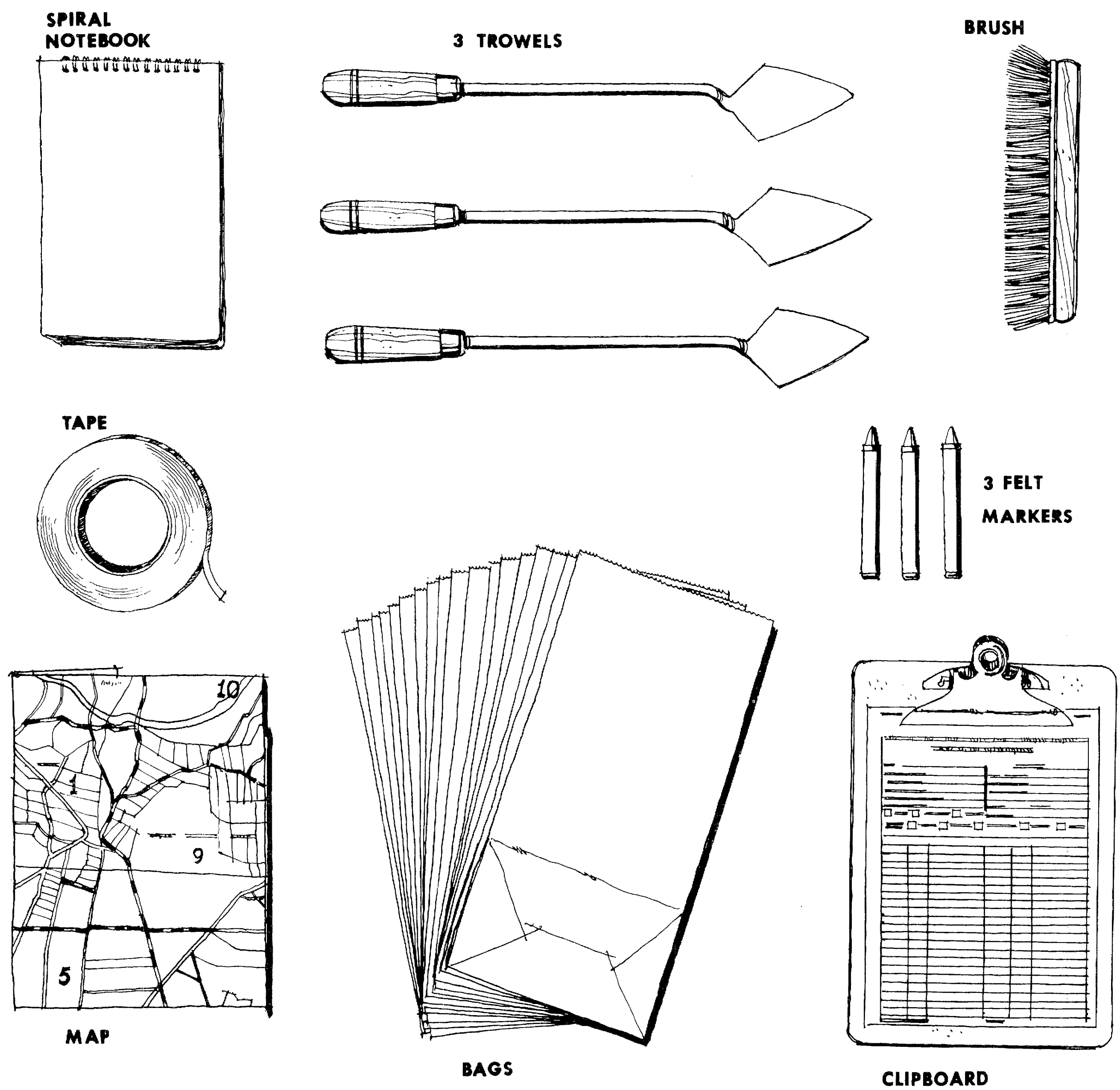


FIGURE 14.—Soil survey equipment: Notebook; pointing trowels; bristle brush for cleaning shoes and equipment; tape for sealing bags; felt markers; map of area to be surveyed; No. 12 wet-strength fungusproof, double-wall bags; and record forms.

N–9204

FIGURE 15.—Plant root examination for nematode cysts.

Plant-Root Examination

The following method of examining potato roots for nematodes may be used to advantage under certain conditions. The best time is while the nematodes are in the white or orange stage. On Long Island this is about the last 2 weeks in June. The cysts are generally in this stage when the potatoes begin to blossom. Fields are looked over carefully, and patches showing plants with weak, spindly stems and stunted tops are selected. Plant-root examination should also be made around buildings or where grading debris has been disposed of. The plant is carefully removed from the ground with a pointing trowel. The roots are separated from the soil, but no attempt is made to remove soil that is clinging to individual roots, as unnecessary handling causes the nematodes to fall from the roots (fig. 15). With the aid of a hand lens, the root system is examined carefully for female cysts. Specimens collected in this manner are placed in vials containing 15 percent formalin or equal parts of rubbing alcohol and water, labeled, and sent to the laboratory for determination.

Labeling and Recording

It is very important that samples be properly labeled and adequate records prepared to clearly identify the samples from each property inspected. Each sample should be labeled in such a manner that all information is visible after the bag has been sealed (fig. 16). The inspector's collection number, which consists of his initials followed by a number, is recorded on the top of the sealed bag. For example, the first collection made on a survey in the calendar year is No. 1. Each collection thereafter, regardless of the State or county, is numbered in a series for the same calendar year. Thus, the inspector's first collection appears as "RAL–1," his second collection "RAL–2," and so on throughout the year. The name of the farmer, the map designation, or the field number is placed on the second line. The date is recorded in the lower right-hand corner of the bag. As the samples or bags of soil are collected in a given field, they are also numbered in a series beginning with No. 1. On the last sample in a series from a particular farm, the notation "End" is made following the sample number.

The collected soil sample is only as good as the records kept of its origin. Thus, in addition to labeling the collected sample another important step in any survey is good recordkeeping (fig. 17). If the collected sample is found in the laboratory to contain golden nematode cysts, one should be able to return to the location in the field from which the sample came. A field survey form should be kept and it should include all necessary details, such as the date sample was collected, collection number, acres surveyed, number of samples

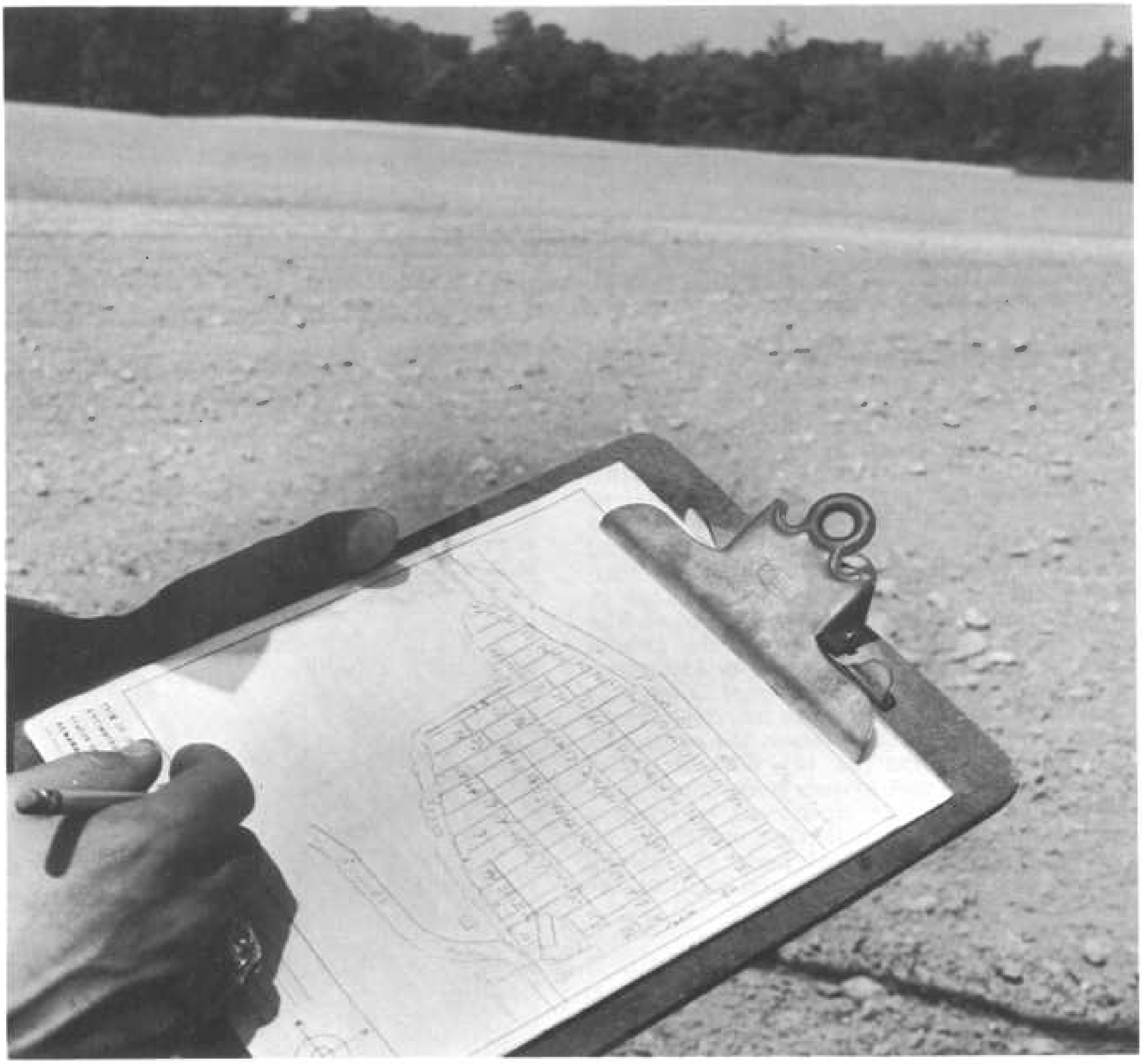
N–38185

FIGURE 16.—An important job of the survey crew is to see that bags are properly labeled.

collected, survey pattern—that is, 8 × 8, and so forth—name of farm operator, mail address, field location including map designation (if any), State, county, and the names of the inspectors that collected the samples (fig. 18). On the reverse of the survey form a sketch should be made of the field, showing the property location, definite landmarks, and the location in the field from which each sample was collected.

Sanitation

Every reasonable precaution should be taken to prevent the spread of this organism. Vehicles assigned to a survey should not be permitted to enter any property. They must remain on highways or thoroughfares, and must be kept clean at all times (fig. 19). Trowels must be free of soil collecting recesses and grooves and should be cleaned when taken from a field. The inspector should clean his shoes with a



N–38191

FIGURE 17.—A sketch should be made of the field to show the property location, land marks, and location in the field from which each sample was collected.

PPC 3-12
(4-57)

U.S. Department of Agriculture A.R.S. Plant Pest Control Division

CYST NEMATODE SURVEY

GOLDEN ☐ SOYBEAN ☐ OTHER ______

DATE 7/18/67 SHELF NO. 31-32 B

MAP DESIGNATION 52-W-7 FARM OPERATOR JOHN DOE

COLLECTION NO. R.A.L. 176 MAIL ADDRESS 100 WEST ST. & RURAL AVE.

ACRES SURVEYED 25 FIELD LOCATION N.E. COR. WEST ST. & RURAL AVE. RURALTON

NO. SAMPLES COLLECTED 34 STATE N.Y. COUNTY NASSAU

SURVEY PATTERN 8 x 8 INSPECTORS BENNETT - JONES

Initial ☑ Confirmatory ☐ Delimiting ☐

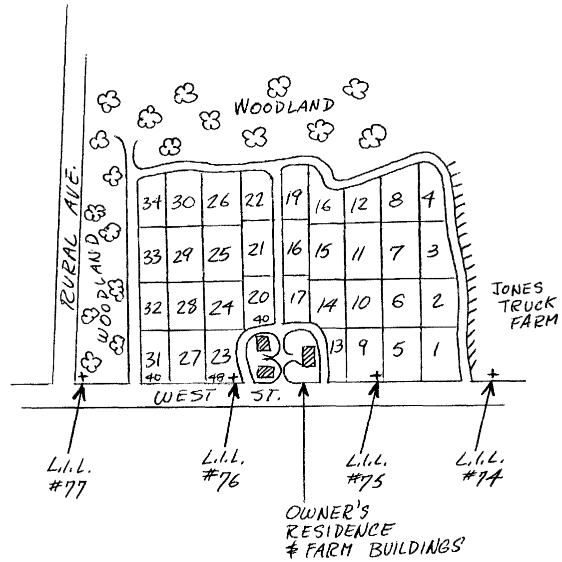
KIND OF SURVEY: PLANT ☐ NURSERY ☐ CROPLAND ☐ SOIL ☐ GREENHOUSE ☐ OTHER ☐

POSITIVE SAMPLE NO.	NO. OF CYSTS	IDENTIFICATION NO. OF SLIDES & VIALS FILED	POSITIVE SAMPLE NO.	NO. OF CYSTS	IDENTIFICATION NO. OF SLIDES & VIALS FILED
13	1	A 17-20 H. ROS.			
14	5	5 CYSTS - VIAL 12			

DETERMINED BY D. O. Betz DATE 12/5/67

DO NOT WRITE IN THIS SPACE

ALL SAMPLES ARE 48 x 72 PACES APART UNLESS OTHERWISE SHOWN



TYPE OF CROP(S) ON PROPERTY 25 ACRES OF POTATOES

ESTIMATED ACREAGE OF EACH ______

STATUS OF FIELD AT TIME OF SURVEY HARVESTED

REMARKS ______

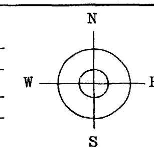


FIGURE 18.—*(Left)* Front of Plant Pest Control form PPC 3-12 used for recordkeeping in nematode survey. *(Right)* Back of form PPC 3-12, showing how form is used to identify samples collected from a farm.

N–38189

FIGURE 19.—All vehicles must remain on highways or thoroughfares.

brush when he leaves fields or storage houses (fig. 20).

Laboratory Procedures

Procedures outlined for recovering nematode cysts from soil samples are based on the fact that dry cysts will float in water. A machine has been developed by ARS, USDA, to float out these cysts and separate them from most of the extraneous material. To prevent contamination, equipment is thoroughly washed after the processing of soil samples from each field; shelves and racks bearing samples are brushed and washed before being reloaded with new samples (fig. 21); when infested material is found, sieves in use at the time are replaced until they have been thoroughly cleaned and inspected.

Testing sieves currently in use are made from medium-gage tin and brass screening by tinsmiths. The sieves are 4 inches deep. The bottom diameter is 10½ inches. For this purpose such a sieve is superior to the factory-made nesting type of testing sieves, because it has a greater capacity and is more rugged.

N–38190

FIGURE 20.—Survey crews should clean shoes and equipment thoroughly before proceeding to the next property.

N-38209

FIGURE 21.—Storage racks containing soil samples for processing.

Soil Processing

The identity of every soil sample must be maintained throughout the washing procedure. It is important that the beaker bears the same number as the sample and that the technician makes certain that he is washing the sample into the proper beaker (fig. 22).

Before a sample is introduced into the soil processing machine (fig. 23), the slow overflow valve (No. 5) is opened. This keeps the apertures through which the water enters the flotation tank from being contaminated and clogged with soil. By the time the paper bag containing the soil is opened, enough water is in the flotation tank so that the fast acting overflow valve (No. 6) may be opened and the soil introduced (fig. 24A). The fast valve serves to roil and stir the soil. This action is best obtained if the soil is poured in gradually. The fast valve is closed as soon as material starts to overflow into the top sieve.

Overflowing is allowed to continue until the water runs fairly clear or until no floating material can be seen on the surface. Material clinging to the sides of the tank is dislodged and directed through the overflow spout with the hand spray (No. 14). The spray should be directed laterally along the surface of the water so it will not submerge floating particles (fig. 24B). Material in the top sieve should be sprayed thoroughly with the hand spray to

N-38210

FIGURE 22.—Soil samples are washed and residues placed in beakers. Identity of every soil sample must be maintained throughout the laboratory processing.

wash cysts through to the screen below (fig. 24C). Tests have shown that cysts tend to become trapped in the coarse material in the top sieve.

When the flotation tank is free of floating material, it is emptied and cleaned by turning it upside down and opening the fast overflow valve (fig. 24D). The tank is then allowed to pivot back to its normal position and the spout is washed outward with the hand spray. Be sure the tank is washed clean.

Again, the material in the top screen is washed, using full force on the hand spray. The screen is then held over the sink and all surfaces washed, inside and out, with the hand spray. Using medium force from the hand spray, the material in the bottom sieve is washed and then transferred to a 600-ml. beaker until the beaker is about three-fourths full (fig. 25A). This sieve is washed and sprayed in the same manner as the top sieve (fig. 25B). After each screen is washed, its holding receptacle should be sprayed clean. The shelf holding the beaker should also be sprayed clean after each transfer of material to a beaker.

The machine is now ready for the next sample (fig. 26).

Examination of Soil Samples

The soil samples are examined to recover, for identification, nematode cysts that may be present (fig. 27). The equipment needed includes a microscope (binocular with 15 × magnification), small 80-mesh sieve (about the size of a muffin tin), examining dishes, scalpel, forceps, needle, 50-ml. bulb syringes, 600- and 250-ml. beakers, 500-ml. metric bottles, and a lamp (fig. 28).

Floating material, which has been transferred into 600-ml. beakers by the washers, is poured into the small 80-mesh sieve (fig. 29). While the material is being poured, the beaker is rotated to clear the sides of adhering material. A scalpel is used for transferring this material into the examining dishes. The correct amount of material per dish is about one-half teaspoonful. Using the bulb syringe, particles adhering to the scalpel and sieve are rinsed into one of the dishes. Sufficient water is added to float the material near the brim of each dish. A probing needle should be held in the free hand for use in spreading clumps of material and for closer inspection of cystlike objects.

A standard Syracuse dish may be used for examining screened flotsam; however, a special plastic dish developed by personnel at the golden nematode laboratory is better (fig. 30). The dish is divided into three sections. Each section of the dish is the width of the view through the examiner's binocular microscope.

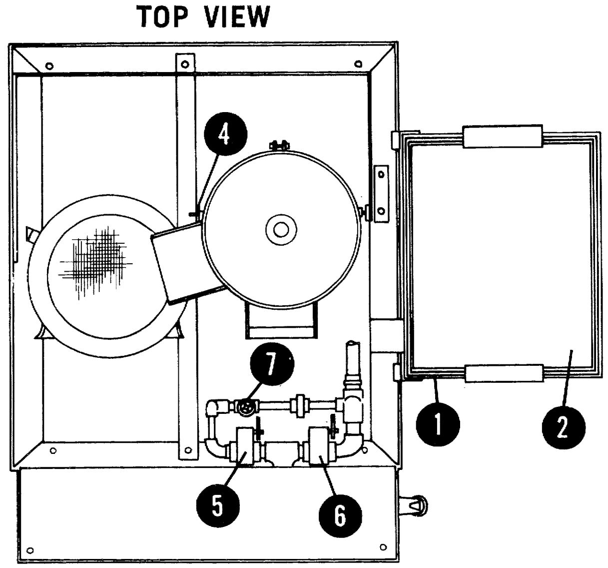
Upon completion of the examination, all equipment is thoroughly washed to avoid contaminating the next sample. Suspect cysts are transferred to frosted dishes or vials and identified with collection and sample numbers. Cysts, or objects suspected of being cysts, should be given to the supervisor. All 80-mesh sieves that have contained positive material must be examined under the microscope before they are used for another sample (fig. 31).

Checking Specimens for Viability

It is necessary to determine whether golden nematode cysts were viable at the time of collection, since quarantine and control action may depend upon such determination. Except for specimens originating in fields fumigated at the level recommended for eradication, the viability of the cysts is based on the appearance of the larvae within. Cysts recovered from areas that were fumigated at the approved

SOIL WASHER ASSEMBLY

1. SINK
2. REMOVABLE WASHER
3. FLOTATION TANK
4. SPOUT
5. SLOW OVERFLOW, VALVE 1
6. FAST OVERFLOW, VALVE 2
7. ADJUSTING VALVE
8. 20-MESH SIEVE
9. 60-MESH SIEVE
10. DRAINAGE BASIN AND SPOUT
11. HOSE FITTING
12. SPLASH SHIELD
13. SIEVE RECEPTACLE
14. HAND SPRAY



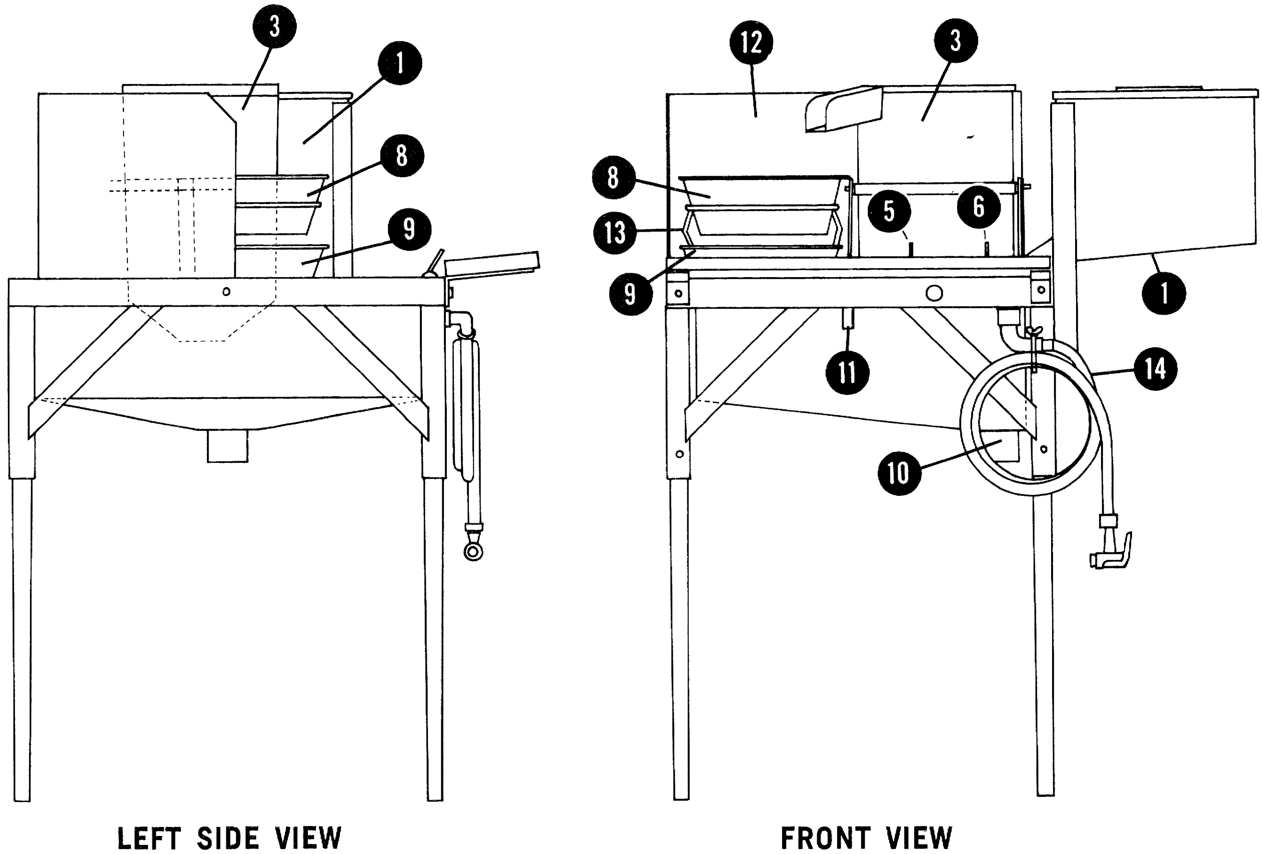
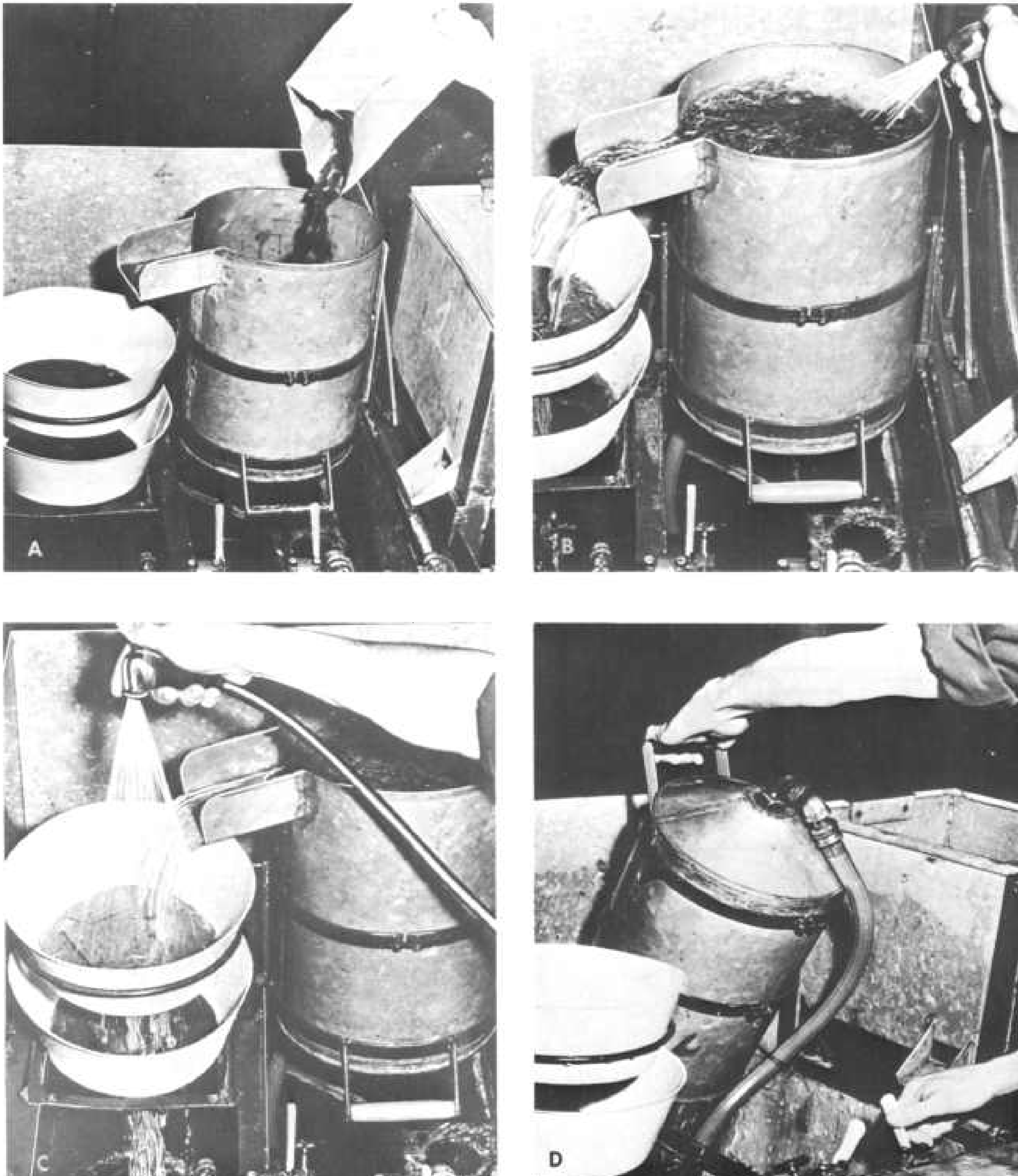
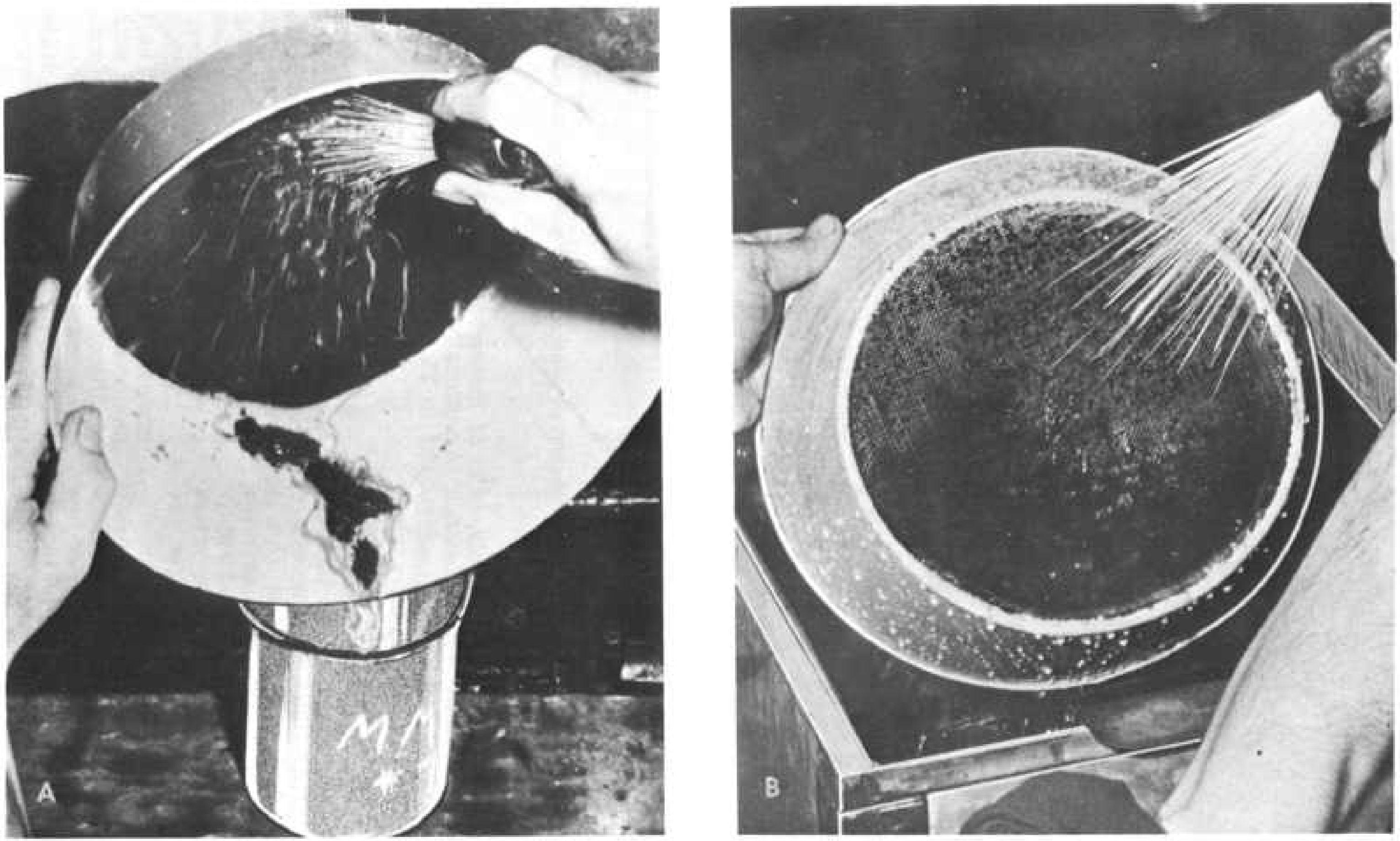


FIGURE 23.—Soil washing machine.



(A) BN-28191, (B) BN-28190, (C) BN-28189, (D) BN-28192

FIGURE 24.—(A) Soil sample being placed into soil processing machine. (B) Surface debris is directed to overflow spout by hand spray. (C) Top sieves are sprayed directly with hand spray to wash cysts through to the screen below. (D) Flotation tank is cleaned by turning it upside down and opening the fast overflow valve.



(A) BN-28194, (B) BN-28193

FIGURE 25.—(A) The washed residue is transferred to a beaker. (B) Each sieve is carefully washed after transfer of flotsam.

N-38212

FIGURE 26.—The machine and all equipment is thoroughly washed after processing the last sample.

level must be examined more thoroughly to determine whether treatment was successful.

The viability of the cysts is determined by placing them in a drop of water on a glass slide. With the aid of a 90-power dissecting stereo microscope and a surgical lance or an iris knife, the cysts are cut open and the eggs and larvae removed. At times it is necessary to rupture the eggs to free the larvae. This is accomplished by placing a cover glass over the drop of water containing the eggs and applying just enough pressure on the cover glass with the eraser end of a pencil to free the larvae.

In those fields where eradication treatments have not been applied, the specimens are considered viable if the internal structure of one or more larvae is intact and there is no indication of any breakdown. In fields where eradication treatments have been applied but the larval specimen(s) is intact and there is no indication of breakdown, further checks must be made to determine that the larva is capable of movement. As the golden nematode is exceptionally sluggish, it may at times take from 1 to 24 hours before any movement is noted.

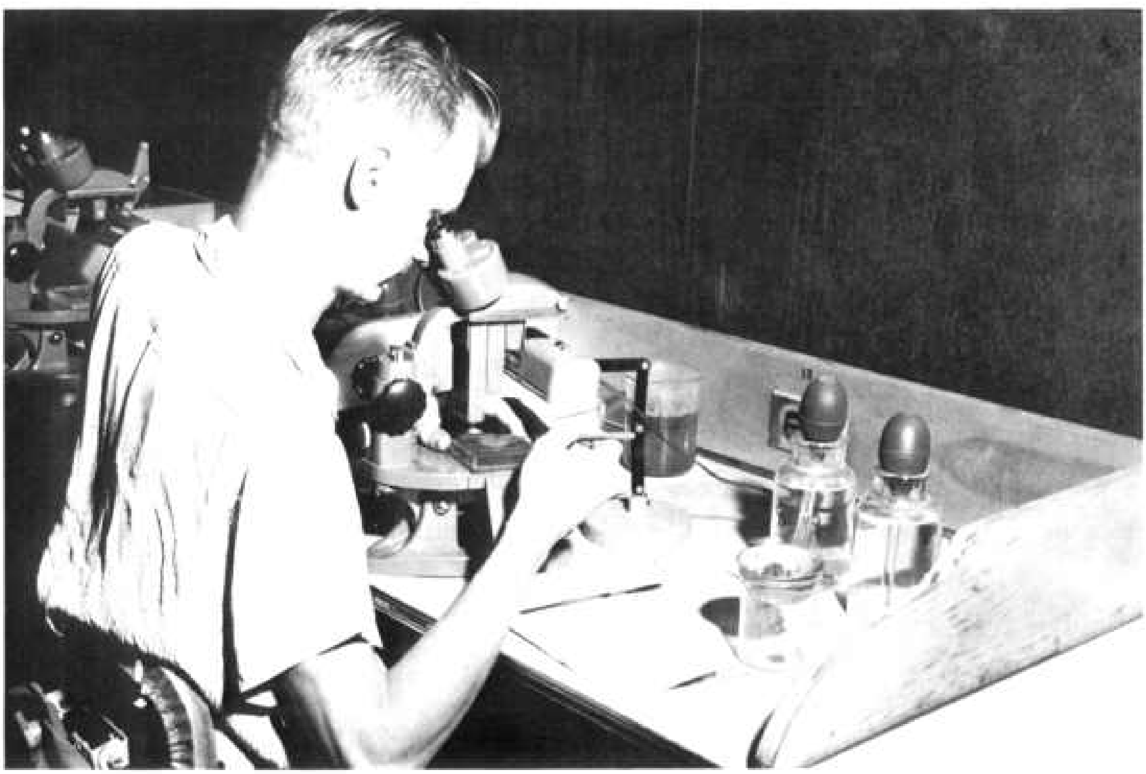
Regulatory

Soon after the golden nematode was discovered in the United States, the New York State Department of Agriculture and Markets, under the broad coverage of the State's "Agriculture and Markets Law" relating to insect pests and plant diseases, took action designed to prevent the spread of the golden nematode. In 1944, the State enacted a specific quarantine against the golden nematode. The quarantine has been modified and amended with changing conditions, receipt of new information, and development of treatments (*28*).

The State's quarantine was drafted in consultation with USDA's regulatory officials. The Plant Pest Control Division has been a full partner with the State and has cooperated in the administration and the enforcement of the quarantine.

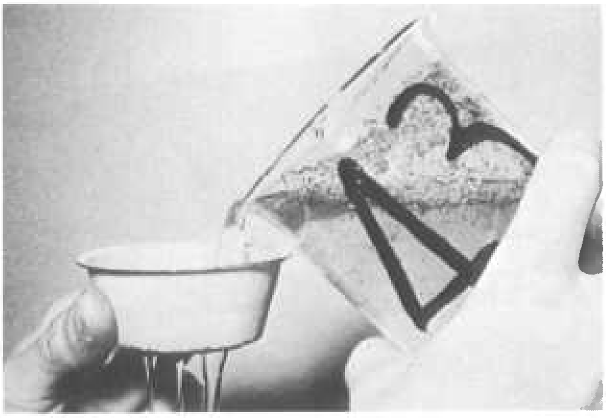
N-38214

FIGURE 27.—Technicians examining flotsam for nematode cysts.



N-38215

FIGURE 28.—Laboratory technician with equipment needed for detecting nematode cysts.



BN–30007

FIGURE 29.—Floating material is transferred from beaker to 80-mesh sieve.

FIGURE 30.—Flotsam is transferred to each section of the dish, and water is added for microscopic examination.

The Golden Nematode Act

In 1948, the Federal Government, through the Congress of the United States, announced the Government's policy for the protection of the potato and the tomato industries from the golden nematode should further action become necessary. The Government's policy was set forth in the Golden Nematode Act, Title 7, U.S. Code, Sec. 150-150g. The act stated, "It is the policy of the Government of the United States independently or in cooperation with State or local governmental agencies and other public and private organizations, associations and individuals to eradicate, suppress, control, and to prevent the spread of the pest." The Secretary of Agriculture is empowered, either independently or in cooperation with States and other agencies, to make inspections, apply suppressive measures, enforce quarantine, enforce restrictions on planting tomatoes and potatoes, destroy tomatoes and potatoes growing in soil found infested with or exposed to infestation of the golden nematode, and compensate growers in areas infested with or exposed to infestation of the golden nematode for not planting tomatoes and potatoes or for losses resulting from destruction of crops. The mandatory restrictions on planting or destruction of crops must be supported by similar State authorizing legislation.

Quarantine

The following are the basic provisions of the New York State Golden Nematode Quarantine:

1. All lands within the boundary of Nassau and Suffolk Counties on Long Island, the towns of Prattsburg and Wheeler in Steuben County, and the town of Italy in Yates County are placed under quarantine.
2. All potatoes grown within the designated area on "clean" land shall be packaged in an approved paper bag or other approved container for movement within the continental United States and Canada (fig. 32).
3. Potatoes grown on lands which become part of a regulated area after planting shall be packaged in paper bags or other approved containers, restricted in movement to approved outlets and moved only under permit, or washed in approved manner under supervision, packaged in paper bags or other approved containers and shall move only under permit, or shall be subjected to such procedures and safeguards which may be prescribed and shall move only under permit.
4. No potatoes shall be grown on any land known to be infested with the golden nematode or dangerously exposed to infestation except where such lands have received a prescribed treatment and have been declared safe, following soil sampling, for growing potatoes.

BN-28899

FIGURE 31.—A microscopic view of golden nematode cysts in flotsam.

5. The golden nematode in any state of development may not be moved or transported except as authorized.
6. There shall be no movement of hay, straw, or plant litter from regulated area except in accordance with an agreement and under permit.
7. Vegetable root crops, transplants, nursery stock, bulbs, corms, and tubers are all subject to appropriate sanitation regulations or treatment when grown on land infested or dangerously exposed to infestation.
8. Potato grading stations shall be operated under permit, which provides for the safe disposal of grader dirt and other waste.

9. Top soil and sod shall be moved under permit only to designated locations in accordance with an agreement and under permit.
10. Used farm equipment, construction, equipment, used containers or any other articles that may be contaminated shall not be moved from the area until they have been disinfested in accordance with prescribed procedures and a permit issued.

Approved Regulatory Treatments

Portable steam generators mounted on pickup trucks are used for cleaning farm machinery. Methyl bromide may be used to fumigate equipment, burlap bags, tools, crates, or other contaminated materials. The following treatment schedules have been worked out for freeing materials and commodities from the golden nematode.

ST 617-4

FIGURE 32.—All potatoes on Long Island are shipped in nonreusable paper bags.

Type of enclosure or material to be treated	*Temperature (° F.) of enclosure or material*	*Exposure period (Hr.)*	*Treatment*
Chamber or tarpaulins	60° or above	16	23 lb. methyl bromide per 1,000 cubic feet.
Chamber or tarpaulins	60° or above	2	46 lb. methyl bromide per 1,000 cubic feet.
Vacuum chamber (27 inches sustained vacuum).	60° or above	16	8 lb. methyl bromide per 1,000 cubic feet.
Gastight chamber (less than 10 cubic feet).	60° or above	3	1 lb. methyl bromide per 1,000 cubic feet.
Gastight chamber (100 cubic feet or more).	60° or above	3	4.6 lb. methyl bromide per 100 cubic feet.
Gastight chamber (100 cubic feet or more).	60° or above	16	2.3 lb. methyl bromide per 100 cubic feet.
Dry oven (preheat)	221°	1	Dry heat.
Dry oven (preheat)	237°	¾	Dry heat.
Greenhouse benches or large containers of soil.	180°	1	Live steam injected throughout soil mass.

The following dips have been developed for treatment of bulbs and corms.

Commodity	*Treatment*
Gladiolus corms, hyacinth, iris, or tulip bulbs, and narcissus bulbs.	1-hour dip in 1-pct. aqueous solution of Aaventa 46N or 0.5 pct. for 3 hr. or 0.25 pct. for 6 hr.[1]
Lily-of-the-valley pips	Separate bundles one from another just before treatment begins. Without preliminary warmup, submerse in hot water at 118° F. for 30 min.; follow with 5-min. drain, and finish with 5-min. cooling dip or hosing in tapwater.
Potato tubers	Wash free of soil, then submerge for at least 5 min. in water maintained at a temperature of not less than 132° F.

[1] Request for registration has not been presented in U.S.A.

Compensation

To aid growers whose income was drastically cut because infestations were found on their farms, the State of New York enacted legislation in 1946 to compensate them for withholding their lands from potato and tomato production.

Funds for this purpose were provided solely by the State of New York until 1948 when the Golden Nematode Act was passed by the 80th Congress. This act authorized Federal participation in an owner-operator compensation program. In 1948, Federal and State funds were made available for payments to owner-operators at the rate of $150 per acre, each cooperator paying $75 per acre. Under an agreement, the State assumed full payment to renters on the basis of a fair rental value as determined by the Commissioner of the New York State Department of Agriculture and Markets.

In 1950, payments to owner-operators were reduced to $120 per acre, each cooperator paying $60. In 1951, payments were reduced to $80 per acre, each cooperator paying $40. In 1952 and 1953, the payments were $60 per acre, Federal and State Governments each paying $30. In 1953, the State of New York and the U.S. Department of Agriculture agreed that the Federal Government would withdraw from the compensation program but would increase its participation in surveys and certain regulatory activities. Beginning in 1954, the State of New York assumed the total cost of the compensation program, paying owner-operators of infested land $60 per acre.

The compensation program provided a very useful means whereby farmers were able to adjust farm operations. Growers were encouraged to plant their infested potato land to pasture, small grain, or field corn. The growing of these crops entitled the grower to receive compensation; however, if he elected to grow high-value crops, such as vegetables, compensation payments were not made.

With the advent of the field soil fumigation program in 1955 and the returning of potato land to production, the need to compensate growers no longer existed and the amount of compensation paid to growers decreased to a very low level.

Chemical Control

The golden nematode is one of the most difficult of all crop pests to kill by fumigation, since the unhatched nematode is protected by both the shell of the egg and the tough, leathery cyst wall of the female.

Many chemicals have been tested by ARS (*8, 12*) and Cornell University for control or eradication of the golden nematode (*27*). The nematocide dichloropropene-dichloropropane has consistently given the most promising results (*42*).

The first large-scale attempt at chemical control or eradication of the golden nematode was in 1946, when the soil fumigant D-D was applied to 1,500 acres of infested land in Nassau County, N.Y. The chemical was applied at the rate of 45 gallons per acre in a single application. Although this application reduced viable nematode populations to a very low level, complete control was not achieved. The concentration of fumigant in the upper inch or two of the soil was not sufficient to kill the organism at this level (*39*).

Scientists generally agree that the dispersal rate of soil fumigant vapors on reaching the soil surface increases because of lack of restraining pressure, and the organisms on or near the surface are not exposed to toxic gases long enough for all of them to be killed.

This factor was taken into account when field tests were resumed by the author in 1955 (*42*). (See table 3.). The same soil fumigant, D-D, was applied, but this time at the rate of 90 gallons per acre in two applications of 45 gallons each, 10 days apart; the soil was turned between applications. These tests, conducted over a period of 5 years, demonstrated that the golden nematode could be controlled, and served as the basis for the treatment program inaugurated on Long Island in 1960 (*41*) (fig. 33).

TABLE 3.—*Number of infested fields and net acreage treated with nematocides and treated acreage released for use, Long Island, 1955–67*

Year	Treated with nematocides: Number of fields	Treated with nematocides: Net acreage	Gross acreage released for use
1955	3	35.05	0
1956	3	47.78	10.00
1957	1	7.00	0
1958	1	13.50	10.61
1959	4	62.83	67.32
1960	13	574.93	656.31
1961	17	1,163.53	1,275.63
1962	23	783.42	783.11
1963	15	489.20	511.50
1964	15	498.96	360.04
1965	15	381.31	240.87
1966	21	764.52	429.14
1967	6	267.72	44.20
Total	137	5,089.75	4,388.73

A group of farmers and businessmen representing the potato industry on eastern Long Island inaugurated a treatment program in 1960 on potato fields exposed to infestation. This organization, known as the Suffolk County Agricultural Commission, was created through the assistance of the county executive and the Suffolk County Board of Supervisors.

The purpose of this organization is to apply nematocides, as a preventive measure, to po-

N-38173

FIGURE 33.—Applying nematocide to infested field on Long Island.

tato fields exposed to infestation but in which no infestation can be detected.

Many growers have multiple farming operations. Upon the discovery that one of these fields is infested, all the other fields farmed with the same machinery are classified as exposed to infestation. Certain potato fields in close proximity to known infested fields may also be classified as exposed.

The nematocide Vidden D applied in a single treatment at 45 gallons to the acre is used. The treatment program is supervised by a representative of the New York State Department of Agriculture and Markets and the Agriculture Department of the Suffolk County Extension Service. The program is financed from funds available through county and local sources. A total of 2,226 acres of exposed land was treated from 1960 through 1966.

Research by Cornell University nematologists has shown that the chemical 1,3-dichloropropene, 1,2-dichloropropane, and related hydrocarbons (80 pct.), and methyl isothiocyanate (20 pct.), marketed under the trade name Vorlex, is effective against the golden nematode. When applied in a split application of 10 gallons each for a total of 20 gallons per acre, Vorlex results in nematode control equal to D-D and Vidden D applied in a split application of 45 gallons each for a total of 90 gallons per acre.

Vorlex, like D-D and Vidden D, is a corrosive material, and natural or synthetic rubber tubing and gasket on applicators must be replaced with chemical-resistant materials. The volatility of Vorlex is similar to D-D and Vidden D. Unlike D-D and Vidden D, Vorlex has the advantage of effective nematocidal action at temperatures as low as 40° F. However, when the fumigant is applied at lower temperatures, 2 or 3 weeks must be allowed for the fumigation period. At temperatures of 60° F. or above a fumigation period of only 7 days is needed.

The chemical is injected into the soil at a 6-inch depth with chisel spacing on the applicator set for 8 inches. Mechanical adjustments to the applicators are needed for this low-volume rate.

Field tests are being conducted with Vorlex during 1968.

Chemicals To Be Used

A chlorinated propane-propylene mixture—consisting of chlorinated C_3 hydrocarbons (100 pct.), 1,3-dichloropropene, 1,2-dichloropropane, and related compounds—is available commercially as D-D and Vidden D.

This chemical is toxic to living plants. Do not apply it within 18 inches of planted crops. The fumigant is toxic to humans and animals if they are exposed directly to it. However, there is no hazard to animals or human health and no residue will result on crops when the chemical is applied as directed on the label.

The fumigant is highly corrosive to metals, particularly aluminum, magnesium, or their alloys. Rubber or rubber-based hoses cannot be used with this fumigant. Only chemical-resistant plastic tubes should be used. Applicators should be thoroughly cleaned of all fumigant before storage. The system should be flushed with equal parts of lubricating oil and kerosene.

Dosage.—Ninety gallons (900 lb.) of approved fumigant per acre (1 gal. weighs 10 lb.) should be applied in two equal treatments of 45 gallons (450 lb.) each, 10 days apart.

Seasonal limitations.—Fields are normally fumigated in the summer and fall and are not available for potato planting until the following spring. This permits the chemicals to dissipate so that toxic amounts will not injure plants or impart off-flavor to tubers and other root crops.

At least 2 months should elapse after the 90-gallon treatment before any crop is planted. A longer period may be necessary if there is much rain following treatment or if the soil temperature drops.

The soil should be fairly moist but dry enough to be tillable. If a ball of soil barely holds its shape when compressed in the hand, its moisture content is acceptable for treatment. Do not apply the chemical when the soil is too wet or too dry.

The temperature of the soil at the time of treatment must be at least 60° F. Best results are obtained at temperatures of 70° and above. Since the air and soil temperatures seldom coincide, temperature readings should be made several inches below the soil surface (*43*).

Equipment Needed

The following equipment is needed to prepare a field for treatment: General farm-type tractor, disk cultivator, moldboard plow equipped with coulter and jointer, and spike-tooth harrow or pulverizer.

The disk cultivator is used to chop stubble and stalks before plowing or to break up clods after plowing. The harrow and pulverizer follow the plow and prepare the seedbed.

To apply the fumigant, the following equipment is needed: (1) A tractor with dual rear wheels, (2) a shank-type applicator with either (3) a gravity-flow system or (4) a variable

N-38184

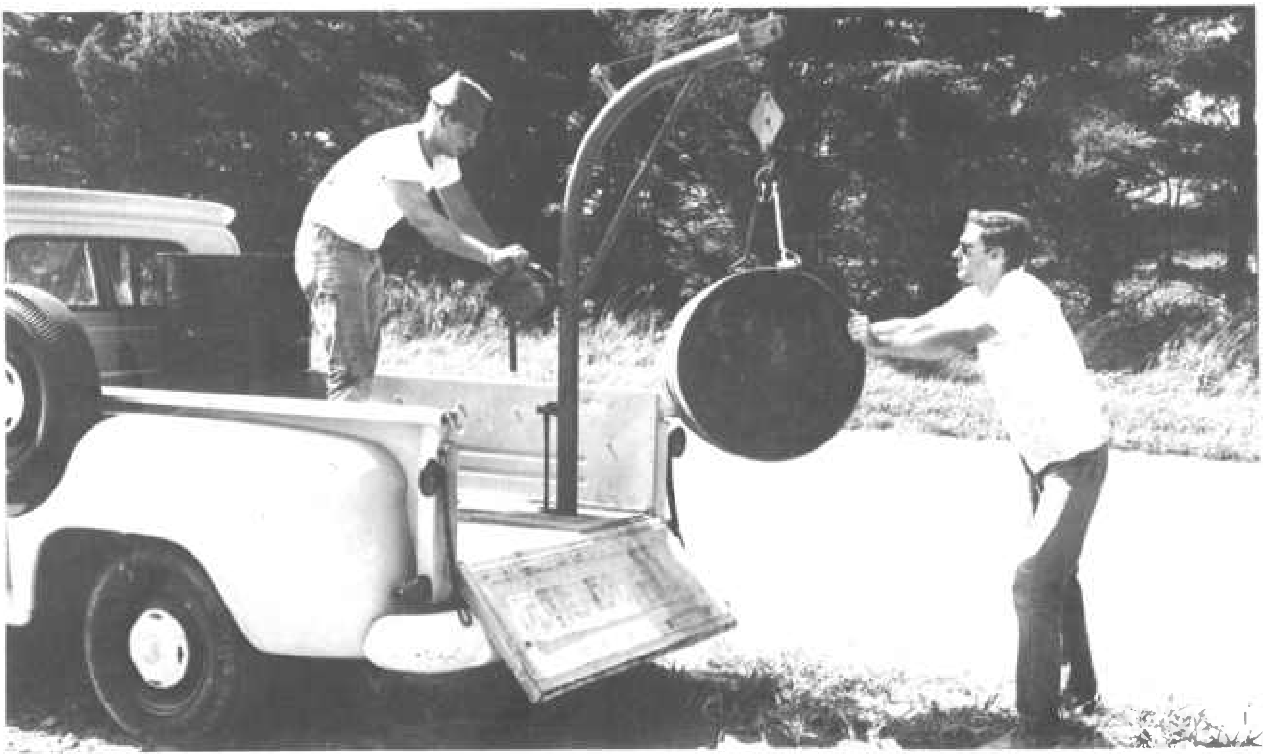
FIGURE 34.—Additional equipment, such as platform lift for moving drums of chemical, is useful.

displacement piston pump to move and meter the fumigant to the shank outlet, and (5) a furrow sealer (figs. 34, 35, and 36).

(1) The tractor used for applying the fumigant should have sufficient power to operate without difficulty at a minimum of 3 m.p.h. The tractor should be equipped with a standard three-point hitch, dual rear wheels, and two 50-gallon spray tanks mounted forward of the rear wheels.

(2) The shank-type applicator presently used in the golden nematode program was originally designed for application of liquid fertilizers. It is composed of a toolbar on which nine spring standards are mounted. Forward-swept shanks and rearward-swept shanks are available; they are interchangeable on the spring standards. The standards should be spaced so that the shanks are 10 inches on centers. A No. 1 integral tool carrier, clamped to the toolbar, permits attaching the applicator assembly to any tractor equipped with a three-point hitch and hydraulic lift control.

(3) The gravity-flow system of moving and metering the liquid fumigant to the shank outlet utilizes a specially vented tank and flow-control coils. This unit eliminates the need for small restricting orifices and pressure pump, and because of the open system, it is less apt to clog. An overflow of the liquid at the vacuum



N–38198

FIGURE 35.—Individual drums of chemical may be moved with a boom mounted on pickup truck.

N–59104

FIGURE 36.—The soil fumigant is rapidly transferred from barrels to tractor by use of an air-cooled gasoline engine.

brake fitting on the assembly will indicate a clogged shank outlet. An instrument panel can be constructed and placed in view of the tractor operator; the panel will indicate immediately a clogged flow line.

(4) The variable displacement piston pump is driven by a trailing ground wheel, or by a sprocket attached to the axle of the tractor (fig. 37). The trailing wheel has wider utilization and is preferred. The liquid is pumped through a flow divider, which distributes the material equally to all discharge lines (fig. 38). Irregular speeds of the tractor do not cause improper discharge; the trailing wheel operating the pump compensates for irregular rates of speed.

(5) It is necessary to seal the furrows made by the shanks and to smooth the soil surface to prevent uneven diffusion of the soil fumigant. The selection and use of a sealer will depend on the types of soil being treated. A Scotch harrow or a suitable drag is attached to the tractor or toolbar and towed behind the unit to smooth and seal the furrows opened by the shanks (fig. 39).

In sandy loam soils on Long Island, a full-length Scotch harrow is used to effect a satisfactory seal.

In fine-textured soils, it may be necessary to use a spike-tooth harrow to obtain the desired seal.

(6) To avoid skips or excessive overlap-

N-38206

FIGURE 37.—Tractor applicator, showing shanks and ground wheel that operates variable displacement piston pumps. The wheel compensates for irregular speed of tractor and results in even discharge of chemical.

ping in application, the tractor operator should use a row marker as a guide. The row marker is attached to the toolbar.

Calibration of Fumigant Metering Systems

Gravity-flow system.—The gravity-flow system can be calibrated by using the following tabulation to determine the milliliters of fumigant per shank for the desired application:

Speed	*Fumigant required*[1] *Ml. per min.*
2.0 miles per hour	573
2.5 miles per hour	717
3.0 miles per hour	860
3.5 miles per hour	1,003
4.0 miles per hour	1,147

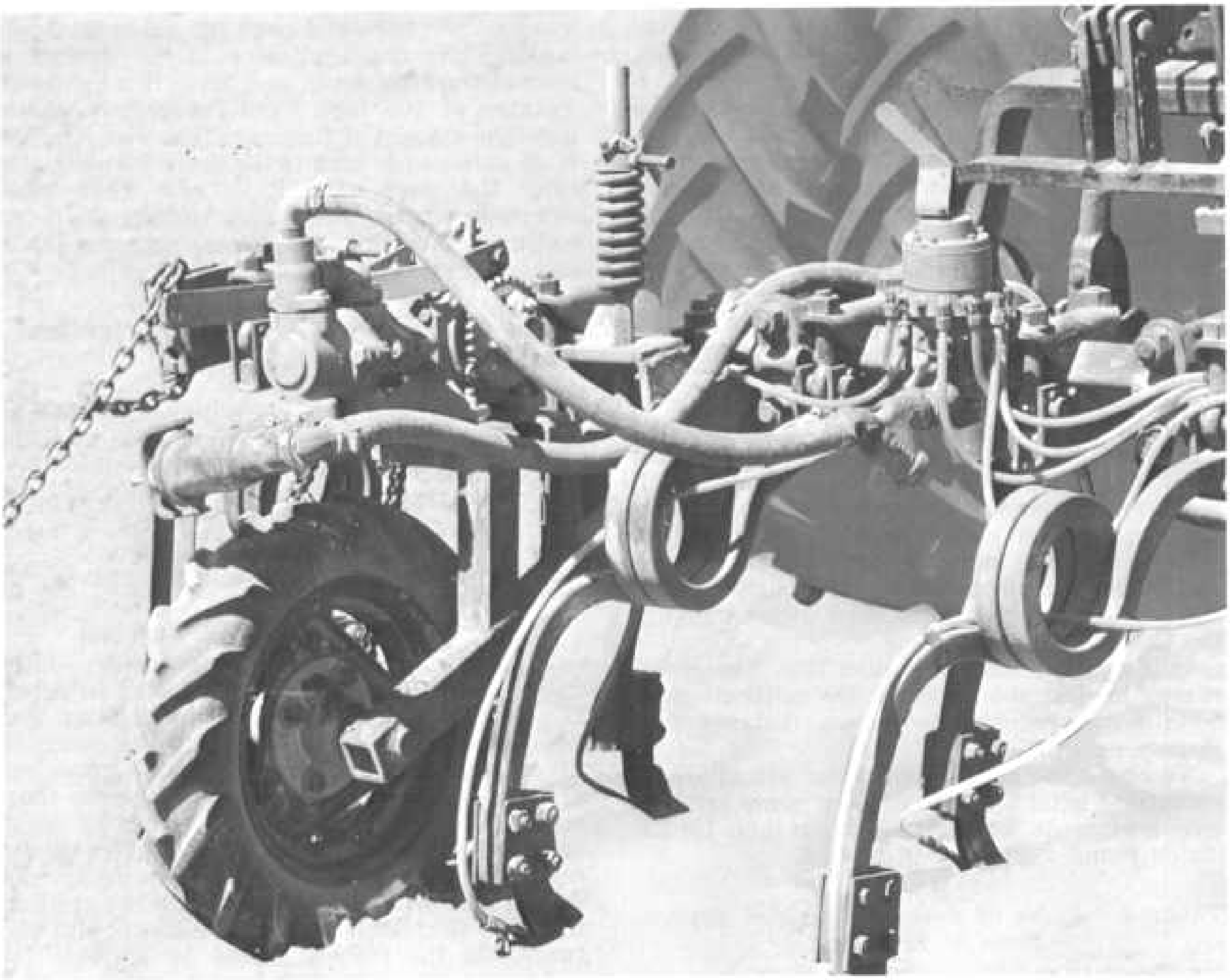
[1] Milliliters required per shank per minute for 45 gallons of fumigant per acre—10-inch shank spacing.

Example: For a 45-gallon-per-acre application with shanks spaced 10 inches apart and the tractor traveling at 3 miles per hour, a flow of 860 milliliters of fumigant is required per shank per minute.

Fill the tank on the applicator approximately half full of fumigant. Make certain the filler cap is screwed on tight so that air cannot enter the tank. Open the control valve and permit the system to run until air can be heard gurgling through the liquid in the tank.

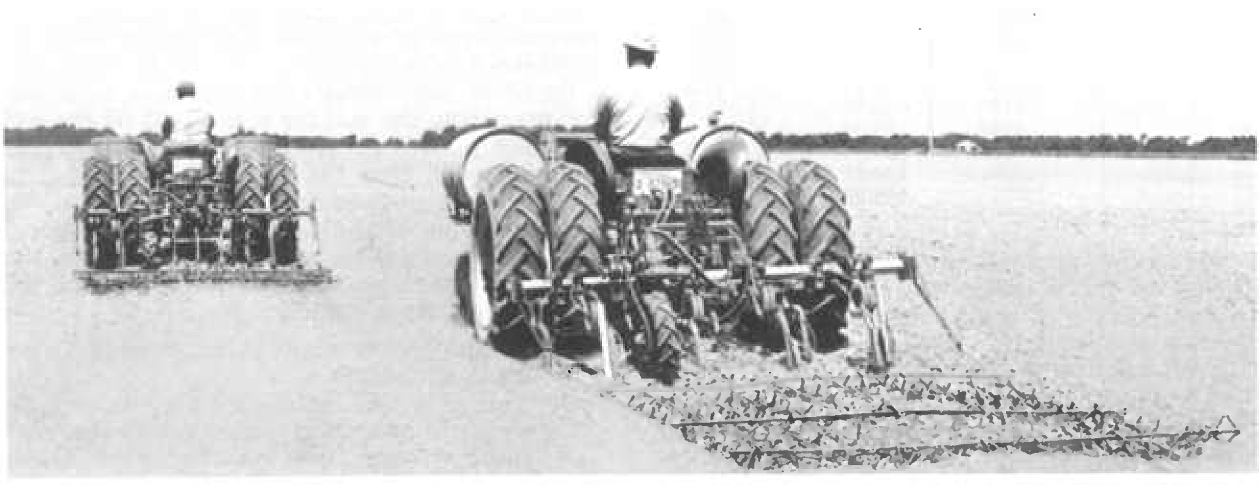
Quickly place a suitable container under one of the shanks for 1 minute, then quickly remove it. Using a graduated cylinder divided into milliliters, measure the amount of fumigant collected. If the amount is less than that specified on the chart, lower the coil flow boom assembly. If the flow is too great, raise the assembly. Continue taking 1-minute samples of the flow until the proper flow rate has been obtained. If the application rate is greater or less than required, the tractor speed may be changed to provide the proper dosage. If this is not practical, another set of flow regulating coils may be installed. Longer coils will reduce the flow rate and shorter coils will increase it.

Variable piston pump system.—The variable displacement pump is calibrated by changing its piston stroke. The piston stroke adjustment



N–59118

FIGURE 38.—The chemical passes through the flow divider, which distributes material equally through each shank.



N–59111

FIGURE 39.—Tractor applicators working in tandem. Scotch harrow pulled by each tractor seals the furrows opened by the shanks.

is conveniently located on the side of the pump.

Calibration of the piston pump system is simplified by using the John Blue Company LF Pump Setting Chart,[6] Blue Part No. LF-416-B. Use the front side of the computer only, as the information on the back does not apply to this installation. For this treating machine, the loaded radius of the wheel is 13.5 inches and the sprocket ratio 3 to 1. With the nine shanks installed, 10 inches on centers, the swath is 90 inches. These three values will always remain the same for this machine, unless a different size of tire is used, a shank removed, or the spacing of the shanks changed.

Using the LF Pump Setting Chart, set the loaded radius 13.5 inches opposite the sprocket ratio, 3 to 1. Set 90 inches on the swath width scale, and under the arrow read the pump setting opposite gallons per acre.

Since loaded radius, sprocket ratio, and swath will remain the same, the pump setting for any application can be read without changing the computer.

It is possible that tires may slip. Therefore, it may be desirable to check the calibration by moving the machine a known distance and measuring the output.

To check the calibration under actual travel conditions after the preliminary pump settings have been made, use the calibration table for LF piston pump applicator in table 4.

TABLE 4.—*Rates of flow for specified applications of fumigant*

Gallons per acre	Flow requirements for 90-inch swath for distance of 100 feet		
	Gallons	*Ounces*	*Milliliters*
1	0.0172	2.201	65.1
5	.0860	11.005	325.5
10	.1720	22.01	651.0
20	.3440	44.02	1,302.0
30	.5160	66.03	1,953.0
40	.6880	88.04	2,604.0
45	.7740	99.04	2,929.5
50	.8600	110.05	3,555.0
60	1.032	132.06	3,906.0

For other application rates and other distances of travel, compute as follows: Length in feet $\times$ rate in gallons per acre $\times$ 0.651 $=$ volume of output in milliliters.

Each applicator is equipped with a calibration tank and gage. The gage is graduated in ounces. Refer to table 4 to determine the ounces of fumigant required for a particular application rate. Fill the calibration tank to the zero mark on the gage and close the valve to supply tanks. Place the applicator in the ground to normal working depth and drive it a measured distance of 100 feet. Read the gage to determine the amount of fumigant that was released. If 45 gallons per acre is the desired application rate, the gage should indicate that 99.04 ounces were used in 100 feet. Change the pump setting, if necessary, to release this amount of fumigant in 100 feet of travel.

[6] Chart available from John Blue Company, Huntsville, Ala.

Field Operations for Shank Injection Equipment

When shank injection equipment is used to apply the nematocides, four separate and distinct field operations are necessary:

1. Preparation of the soil for first application.
2. First application of the fumigant.
3. Preparation of the soil for the second application.
4. Second application of the chemical.

Preparing soil for first application.—Each field to be treated must be inspected to determine the type and amount of preparation that will be necessary before applying the chemical. If coarse stubble or stalks from a previous crop or weeds are present, they must be thoroughly chopped or disposed of either by decay or by other means. Normally, it requires about 6 months for stalks and stubble to decay to a degree that will not interfere with the application. If the field is disked thoroughly and turned in the fall, it should be suitable for treatment the following spring or summer—with an additional disking and plowing just before treatment.

The type of soil, depth of top-soil, and the normal depth of previous cultivations must be considered when plowing the field. Normally, a depth of approximately 8 inches is sufficient for preparing the soil for treatment. If the soil has been plowed previously to a depth greater than 8 inches, then the soil must be plowed to that depth in preparation for treatment.

Preparation of the soil for the first application of the chemical will usually require the following operations to condition the soil for reception of the chemical:

1. Disked one or more times, depending on trash present.
2. Turned with a moldboard plow to a depth equal to maximum penetration in past cultural operations. Do not plow when soil is too wet or too dry.
3. Disked lightly to smooth ridges and clods.

The soil is ready for treatment when it has been properly plowed and is relatively loose to permit maximum diffusion of the chemical, when it is free of ridges, clods, and debris, and when it contains sufficient moisture to be tillable.

First application of fumigant.—The fumigant should be applied immediately after the soil conditioning operation has been completed, if the correct soil moisture and soil temperature conditions prevail.

The entire area must be covered with fumigant; skips may result in failure. When all the field has been fumigated, make one or more round trips at each end to insure treatment of as much of the headlands, turnaround and other border areas as possible.

Make sure that the fumigant is flowing continuously to each shank. If clogging occurs, stop immediately and make adjustments. When the trouble has been corrected, turn the tractor around and re-treat all the area that may not have received proper treatment. When lowering the shanks into the soil, keep the tractor moving to prevent clogging the flow line outlet with soil.

Preparing soil for second application.—At least 10 days should elapse after the first application before preparing the soil for the second application. As a result of the first application, the texture of the soil is usually in a more suitable condition for treatment. The soil is turned with a moldboard plow at a depth of 1 to 2 inches deeper than the first plowing. The moldboard plow *must* be equipped with a suitable coulter-jointer for this operation. The coulter-jointer is adjusted so that the top 3-inch layer of soil is cut and turned into the bottom of the furrow and covered with the lower layers of soil. This is most important since the fumigant dissipates rapidly near the soil surface, and cysts occurring there during the first treatment may not be exposed to a lethal dose.

A frequent check should be made in the second plowing operation to determine if the top 3 inches of soil are properly turned and covered. This can be accomplished by spreading a 6-inch band of lime on the surface of the soil in advance of and at right angles to the plow (fig. 40). After the plow has passed, dig into the turned limed area to determine whether the lime has been covered to the required minimum depth of 3 inches (fig. 41).

The soil surface should be comparatively smooth after this operation. If it is not smooth, a harrow, drag, or roller should be employed. In any event, the soil should not be disturbed below a depth of 3 inches.

Second application of fumigant.—The second application of fumigant is made 10 to 14 days after the first. The same procedure and technique is used as in the first application. It might be desirable to make the second application at right angles to the first. This will result in a checkerboard treatment of 10-inch squares. The topography of the field will determine which direction to make the second application.

Treatment of border areas.—Any golden nematode cysts remaining along the border of treated fields serve as a potential source of reinfestation. Accordingly, on Long Island the chemical sodium *N*-methyldithiocarbamate, sold commercially as Vapam, is applied to headlands, roadsides, farmyards, and farm roads adjacent to fields that have been fumigated. The object is to kill the nematodes on the soil surface. The Vapam is mixed with water and applied as a drench at the rate of 50 gallons of Vapam in approximately 3,000 gallons of water per acre. Since Vapam is most effective when the soil surface is moist, it is generally applied after a rain. Any apparatus affording high gallonage and low pressure can be used. A boom-type nozzle has been found most practical.

Decontamination of Equipment

All equipment used in the preparation or treatment of an infested field, must be thoroughly disinfected before it is moved from the field to another location. The equipment should be subjected to the prescribed cleaning procedures using steam or methyl bromide fumigation (fig. 42).

Precautions

If pesticides are handled or applied improperly, or if unused parts are disposed of improperly, they may be injurious to humans, domestic animals, desirable plants, and pollinating insects, fish, or other wildlife, and may contaminate water supplies. Use pesticides only when needed and handle them with care.

When using nematocides, follow the manufacturer's directions exactly. Variations in soils and climate may affect the action of the nematocides.

Handle nematocides with extreme care. Avoid prolonged breathing of the fumes. Do not allow the liquid to come into contact with the skin. If the liquid is accidentally splashed on

N-38175

FIGURE 40.—A 6-inch band of lime is placed on the surface of soil to check efficiency of plowing operation.

N-38178

FIGURE 41.—Inspection of the plowed ground determines whether the lime has been covered to the required minimum depth of 3 inches.

N-38183

FIGURE 42.—All equipment used on infested land must be thoroughly steamed clean or fumigated before it is moved to another location.

clothing, including gloves or shoes, remove the garments without delay; do not wear them again until they are washed, cleaned, or at least thoroughly aired for a day or two. Never risk getting the material in your mouth. If it is splashed in your eyes, wash it out with large quantities of water and consult a physician.

Keep children and pets away from fumigated soil. Potting and rooting soil that has been treated with nematocides should not be used until all traces of fumigant odor have disappeared.

Careful disposal of empty pesticide containers and surplus pesticides is an important part of safe pesticide use. Large metal drums can be disposed of more safely and easily by returning to the supplier or selling them to a cooperage firm equipped to handle toxic materials. Small metal drums should be rendered unusable by chopping holes in them or crushing them and then burying them at public dumps.

Resistant Potato Varieties

The potato is one of about 2,000 species in the family Solanaceae. This family includes such plants as tobacco, tomato, eggplant, pepper, horse-nettle, bittersweet, ground cherry, and petunia. Botanically, the potato cultivated in North America, Europe, and other lands is *Solanum tuberosum* L. (fig. 43). There are nearly 160 wild species and 20 cultivated species of the tuber-bearing *Solanums*. All

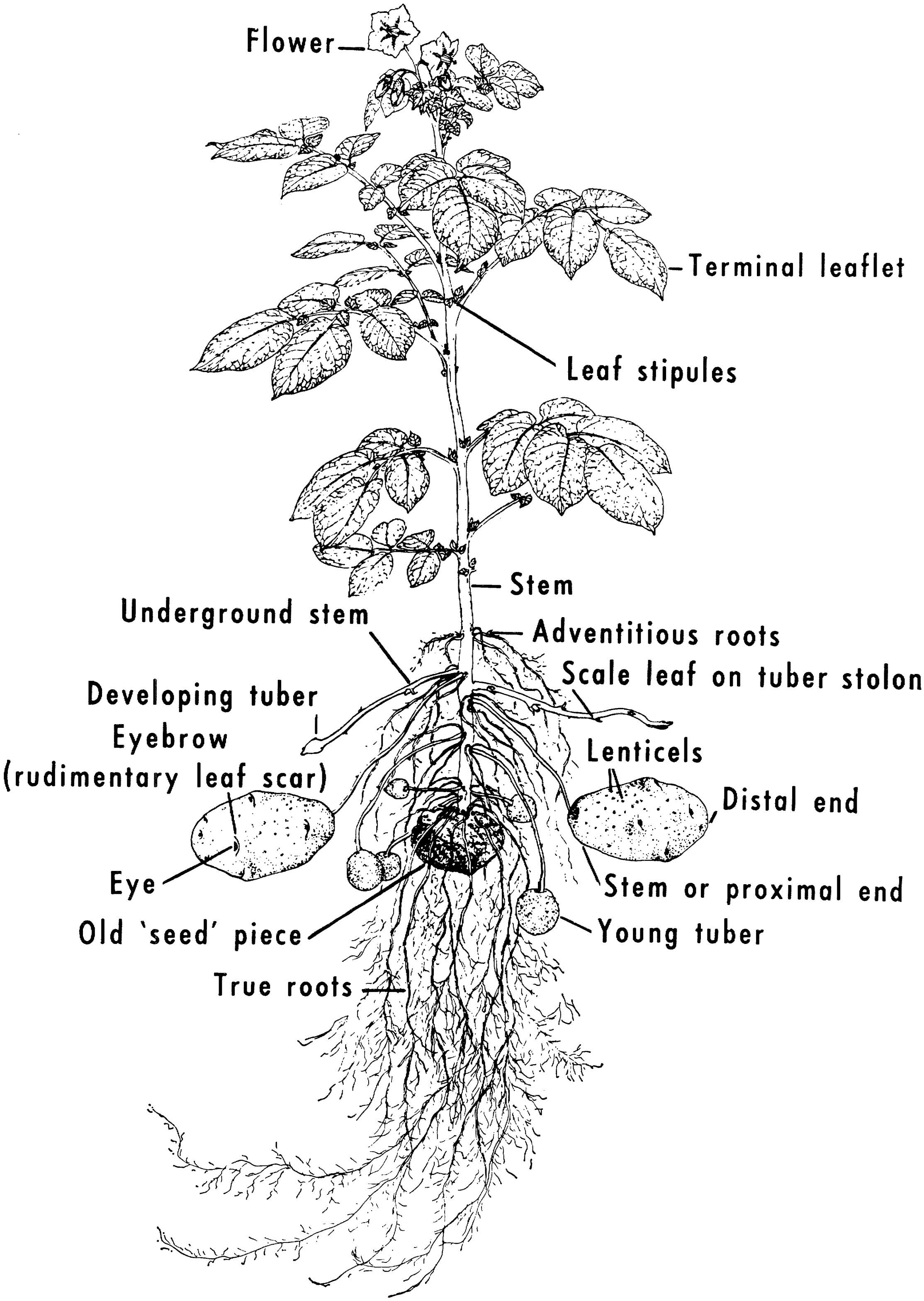


FIGURE 43.—Diagram of the parts of a potato plant. Note that the stolons and tubers arise from stem tissue, and the true roots arise at the base of the stem.

these relatives of the potato are of New World origin. Probably the closest wild relative is *S. andigenum* Juz. & Buk., which produces acceptable yields under the short-day conditions of the Andes Mountains. Some botanists consider *S. andigenum* to be a subspecies of *S. tuberosum.*

A potato breeding program to find resistance to the golden nematode has been carried out extensively in Great Britain, Holland, and Germany, since 1945 when Ellenby, a British scientist, screened many *Solanum* spp. and discovered that *S. vernei* and *S. tuberosum* spp. *andigena* were resistant to the golden nematode (*50, p. 252*). In the United States, Cornell University scientists confirmed Ellenby's findings and, in addition, found that *S. sucrense* also had resistant characteristics. However, *andigena* seem to offer the best basis for a potato breeding program because the resistance of *andigena* potatoes is due to a single dominant gene (*38, p. 265*). A breeding program for resistance involves backcrossing, which is not too involved in this case because no sterility barriers exist between *andigena* and *S. tuberosum.* Furthermore, since potato varieties are reproduced vegetatively there are few problems in fixing the resistance in varieties once it has been transferred from the resistant parent (*38, p. 265*).

Resistant varieties, like susceptible ones, produce a substance that has a high hatching quality. The roots are invaded by the larvae of the nematode in a manner similar to that of larvae invading susceptible varieties. Some males are produced, but few females complete their development to form cysts. Thus, the growing of resistant potatoes on infested land results in a decrease of nematode populations in the soil (*38, p. 265*).

Until the 1950's it was assumed that there was no particular physiological variation in the golden nematode's ability to attack the resistant host (*20, p. 414*). However, in breeding varieties for resistance to the golden nematode, it has been shown that within the nematode species there exist populations with ability to break the resistance and complete their life cycle on the resistant variety. These populations are referred to as resistance breakers or resistance-breaking biotypes (*20, p. 414*). Scientists investigating resistant potatoes in Europe found that the golden nematode from Peru was capable of breaking resistance in 82 Dutch tuber lines bred from C.P.C. 1673 (*20, p. 414*). The names of biotypes are not yet established; however, European workers report that they have obtained evidence of at least six biotypes (*38, p. 265*).

The widespread occurrence of biotypes in several European countries presents serious problems for maintaining potato varieties that are resistant to the golden nematode. *S. vernei* is resistant to all known biotypes; however, plant breeders have found this species difficult to use in a breeding program. The resistance of *S. vernei* is thought to be due to many genes, some of which may be lost in backcrosses of cultivated varieties (*38, p. 265*).

In the United States, both the U.S. Department of Agriculture and Cornell University have programs seeking to develop nematode resistant potatoes. Since the work started (about 1950), these agencies have tested thousands of new potato lines. In February 1966, a new commercial potato variety resistant to the golden nematode was announced. The new variety, named Peconic (fig. 44), is a product of the work of Cornell plant breeders and plant pathologists.

Peconic compares favorably with the popular Long Island variety Katahdin (fig. 45). Peconic is free of defects such as hollow heart and misshapened or oversized tubers. Peconic has been tested and found to be resistant against the race of golden nematode occurring in Newfoundland, Canada (*32*).

Peconic derives its resistance to the golden nematode from the subspecies *andigena.* Resistance-breaking biotypes that are capable of breaking resistance of this type occur in Europe. There is no evidence to date, however, that more than one form of nematode exists on Long Island. The *andigena* resistance is effective against the golden nematode on Long Island (*32*).

In expectation that resistance-breaking biotypes might be developed, plant breeders are conducting research with other species of *Solanum* to find other sources of nematode resistance. In the meantime, the growing of Peconic as a commercial variety will be restricted to infested potato fields that have been fumigated and released to growers for potato production. Peconic may also be used on land exposed to infestation but on which the nematode population has not developed to a level that can be detected by the usual survey procedures.

Thus, the future control program of the golden nematode on Long Island will be soil fumigation of all known infested fields followed by the use of resistant potato varieties.

Peconic is expected to be ready for limited use on Long Island in 1968.

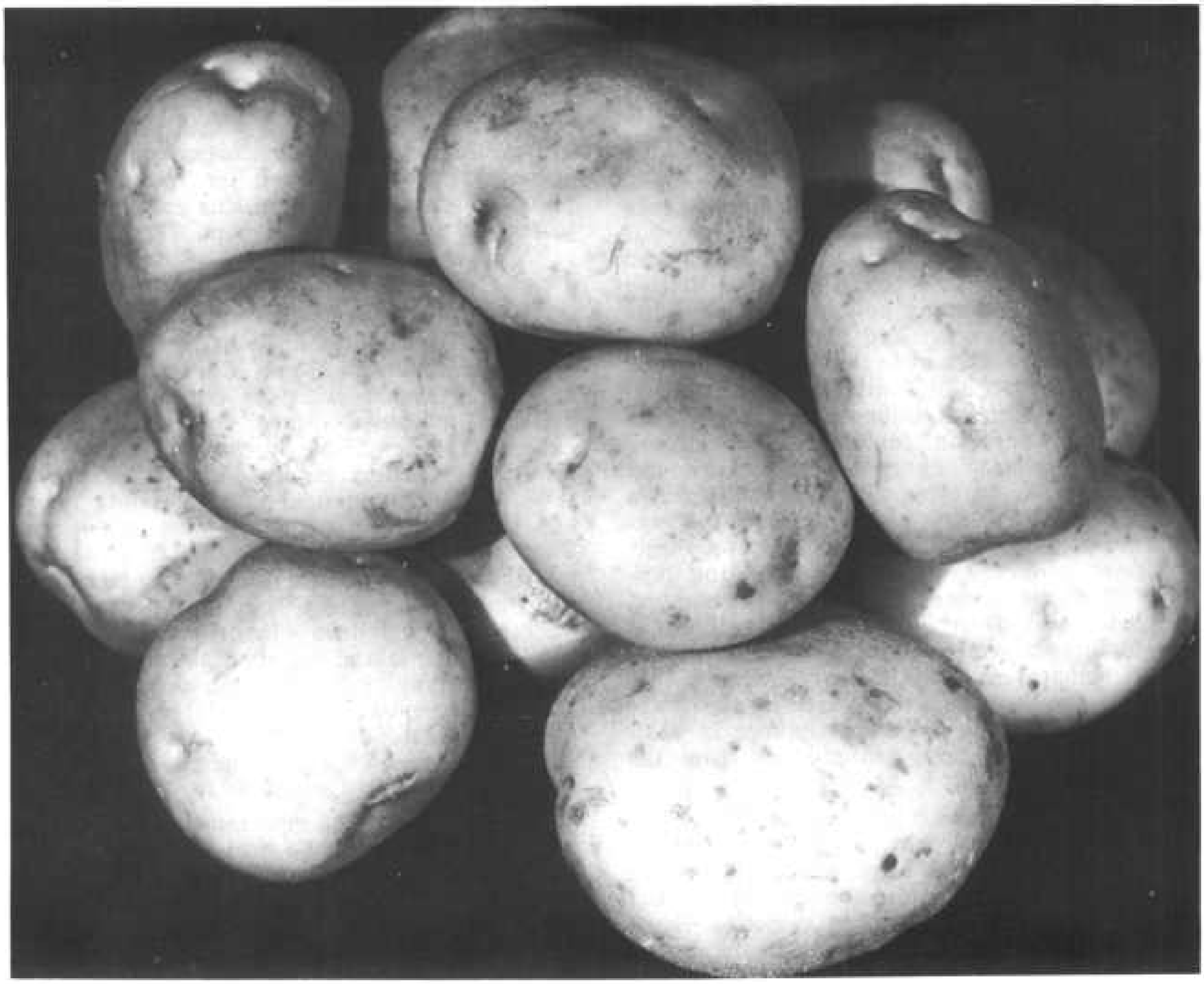


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FIGURE 44.—Peconic, a new variety resistant to the golden nematode, was released February 1966. Peconic has many of the same characteristics as the Katahdin.

BN-30077

FIGURE 45.—Tubers of the Katahdin variety. This variety is widely grown on Long Island and the Atlantic coast.

BN-32356

FIGURE 46.—Wauseon, a new variety resistant to the golden nematode, was released November 1967. Wauseon is also similar to the Katahdin.

USDA plant breeders, in cooperation with Cornell scientists, released in 1967 a second variety resistant to the golden nematode. The new variety named Wauseon is a selection from a cross between B4159-8 and Katahdin. It is resistant to common scab, moderately resistant to Verticillium wilt, highly resistant to the common races of late blight, resistant to latent mosaic and mild mosaic, and to the golden nematode. Its tubers are resistant to net necrosis following leafroll infection. The tubers of Wauseon have smooth skin, are round to oblong, and have shallow eyes and creamy-white flesh (fig. 46).

THE INTERNATIONAL PROBLEM OF CONTROL

The golden nematode is a pest of global concern (figs. 47–51). It is frequently the subject of both domestic and international regulations. The international spread of the golden nematode is a target of import regulations of many countries.

The long-distance shipment of nursery stock, plants, plant parts, corms, and tubers is increasing. The use of air transport to move these products has multiplied the risk of long-distance spread of not only the golden nematode but other insects and plant diseases.

Effective nematocides, such as dips for nursery stock, bulbs, corms, and tubers are urgently needed. The hazards of spreading nematodes are not restricted to plant material alone, as will be seen later in this chapter.

Most countries that have regulations against the golden nematode require that imported agricultural products be free of soil. Most countries have very strict regulations about the importation of potatoes from countries where the nematode is known to occur. Many countries require a phytosanitary certificate showing that the potatoes originated in fields that have been soil sampled with negative results or from a portion of the country where all survey data indicate that the nematode does not exist. In some instances, potatoes are embargoed from countries where the golden nematode occurs. The movement of bulbs, corms, and nursery stock is usually subject to rigid requirements.

The need for uniform measures concerning the control of the golden nematode has been recognized by the European Economic Community (EEC). On October 14, 1966, the EEC Commission submitted proposals to the EEC Council for consideration and adoption.

These proposed regulations were the mini-

FIGURE 47.—Golden nematode infestations in the Western Hemisphere.

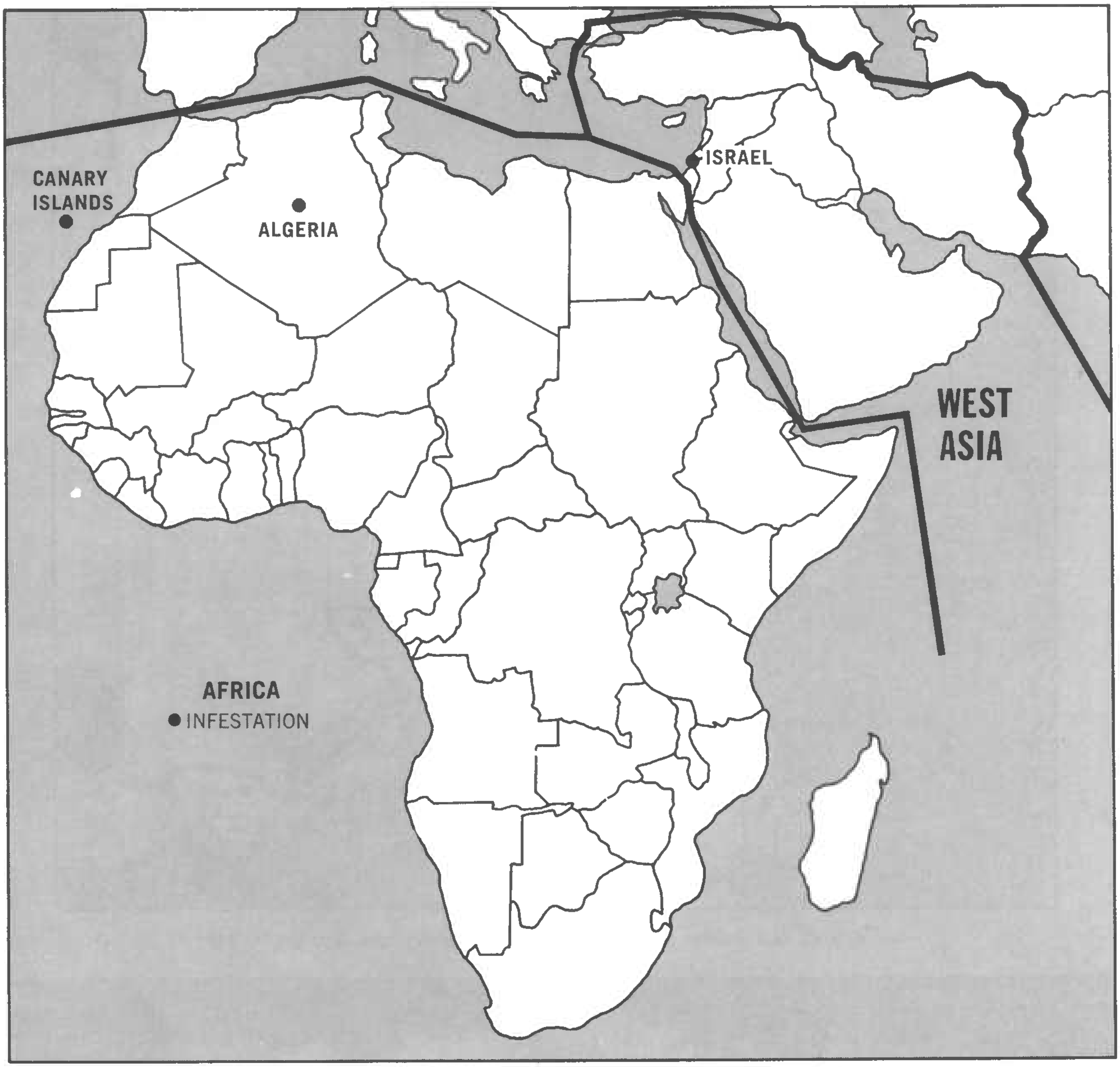

FIGURE 48.—Golden nematode infestations in Africa and West Asia.

mum requirements for the control of the golden nematode and prevention of its spread in member countries. The council recommended that seed potatoes be produced only in areas that have been carefully surveyed and officially declared free of the golden nematode. Upon discovery of an infestation, member countries will conduct such surveys as necessary to find the limits of the infestation. Member countries will prohibit the growing or storage of potatoes or plants for transplanting on infested premises. Member countries will prescribe that potatoes recognized as being contaminated with the golden nematode shall not be used for seed purposes.

These regulations should remain in effect until a determination is made that the nematode no longer exists. The council also recom-

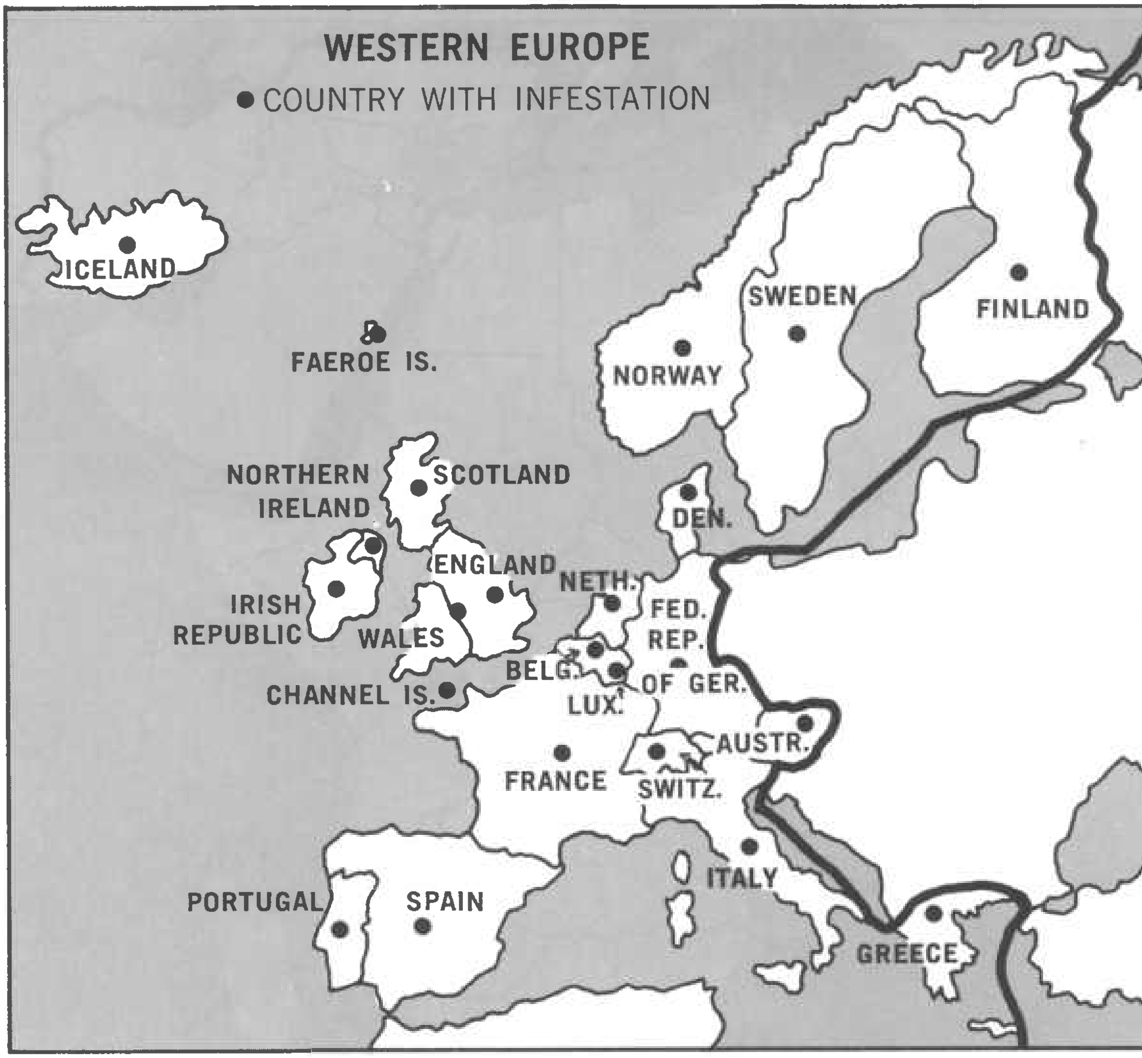

FIGURE 49.—Golden nematode infestations in Western Europe.

FIGURE 50.—Golden nematode infestations in Eastern Europe and the U.S.S.R.

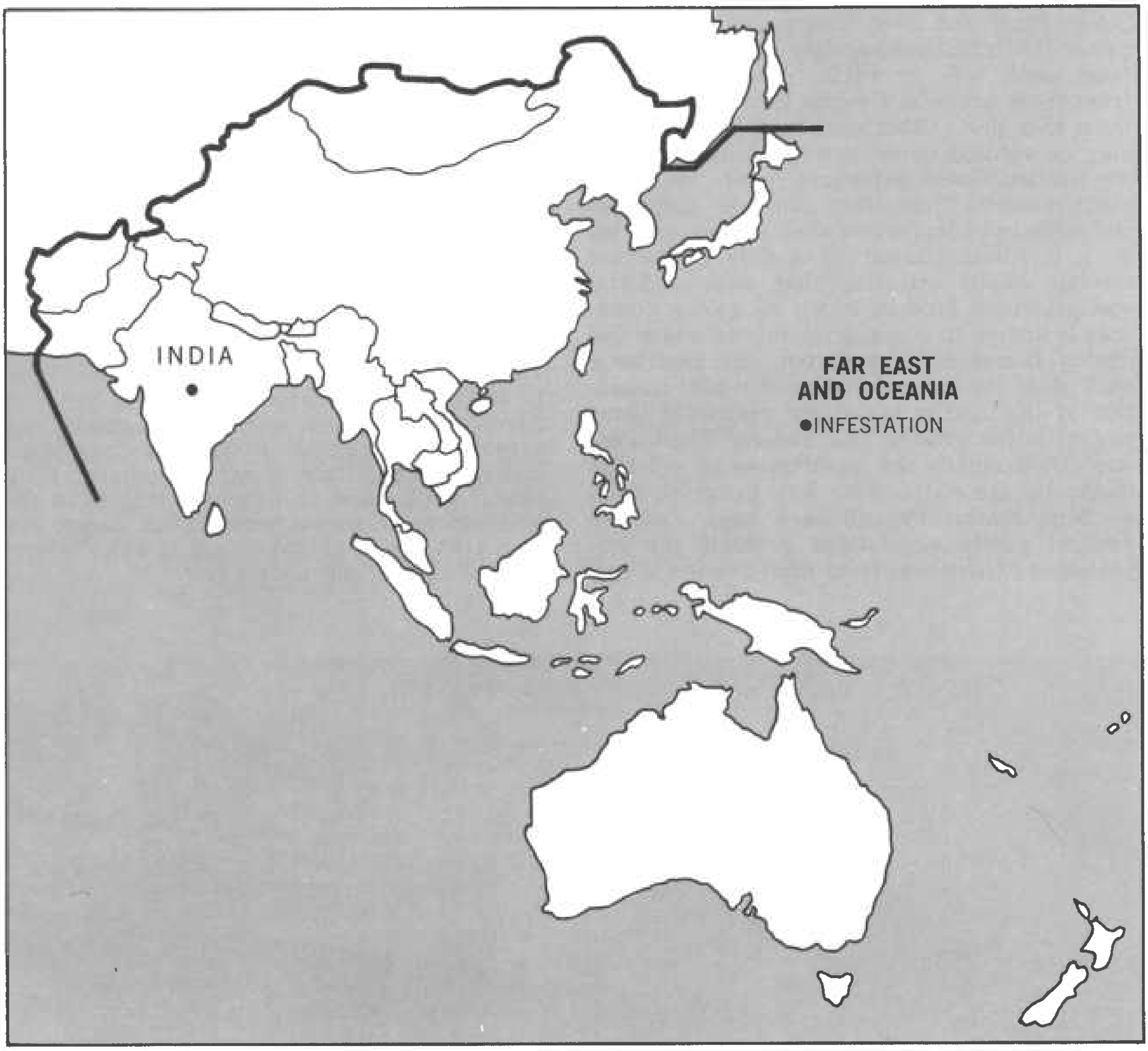

FIGURE 51.—Golden nematode infestations in the Far East and Oceania.

mended that stricter or supplementary regulations be enacted to control or prevent the spread of the golden nematode where local conditions warrant.

The EEC Commission will publish before November of each year a list of resistant potato varieties and the biotype of nematode against which the resistance applies.

The European and Mediterranean Plant Protection Organization, Paris, France, generally referred to as EPPO, has been the leader in Europe in establishing guidelines to be followed in preventing international spread of the nematode (*34, p. 29*). The golden nematode was the subject of a special conference sponsored by the EPPO in the Netherlands in 1955. At that time the member countries recommended requirements for export certification of potatoes. The conferences also recommended the use of a standard soil sampling technique based on the Dutch and United Kingdom methods, which are widely used in European countries (*17*). (See Appendixes II and III.)

To avoid possible importation of the golden nematode into the United States, the Nursery

Stock, Plant and Seed Quarantine No. 37 requires that plant propagative material be free from sand, soil, or earth, except shipments from those areas in Canada known to be free from this pest. Otherwise, such importations may be refused entry into the United States. As an additional safeguard, such restricted plant material from those countries with official systems of inspection shall be accompanied by a certificate issued by a duly authorized foreign official attesting that such material was grown on land in which no golden nematode is known to occur. In countries where the golden nematode is reported, the certificate shall state the date of the most recent inspection of the land in which the restricted plant material was grown. The Federal Plant Pest Act also prohibits the importation of soil that might be associated with any material, such as farm machinery and used bags, and the Federal potato regulations prohibit the importation of potatoes from most foreign areas.

The enforcement of various Federal plant quarantine regulations results in the interception of the golden nematode each year on a wide variety of products and materials. During 1965, the golden nematode was intercepted more than a hundred times: In soil mailed from Ireland; in soil with automotive equipment: (fig. 52); in bagging, conex box, and tractors (fig. 53) in cargo from England, Germany, and Italy; in soil with horseradish in air mail and in ships' stores from England and an unknown origin; in soil with potatoes in air baggage, cargo, and ships' stores from England, France, Germany, Italy, Netherlands, Peru, Scotland, Sweden, and unknown origin; in soil with propagative material in air baggage, air mail, air quarters, baggage, and cargo from England, Finland, France, Germany, Ireland, Italy, Poland, Portugal, Scotland, Sweden, and an unknown origin; in soil with shamrock in air baggage, air cargo, and mail from Ireland; and in soil in ships' stores from England and Germany.

BN-22749

FIGURE 52.—USDA Plant Quarantine inspectors check a returning tourist's car for golden nematode. Contaminated equipment must be steamed clean before entry into the United States.

BN-28128

FIGURE 53.—Although reconditioned and painted, these tractors from Europe were contaminated with golden nematode. Cysts were found on small particles of soil under the paint.

WORLD DISTRIBUTION OF THE GOLDEN NEMATODE

Algeria

In March 1953, symptoms of golden nematode damage became apparent near Algiers. A survey was made of all potato- and tomato-growing areas in the vicinity of Algiers. This was a plant-root survey with some soil samples taken. Eight communes in the vicinity of Algiers were found infested. This is a coastal zone where often two and sometimes three successive potato crops are grown in one year on the same field. Accordingly, several periods of cyst formations are observed from March to December.

About 1,900 hectares (4,750 acres) of winter potatoes (harvested March to May) and 930 hectares (2,325 acres) of summer potatoes (harvested November and December) are produced in this area. The country produces approximately 10,700 hectares (26,750 acres) of winter potatoes and 13,500 hectares (33,750 acres) of summer potatoes.

In certain communes where infestations are heavy, potato production has been reported to be reduced 50 percent, from 130 to 150 quintals per hectare to 50 quintals per hectare (from 28,660 to 33,069 lb. to 11,023 lb. per acre).

Regulations are in effect for the movement of commodities capable of carrying the pest. There has been some decrease in the intensity of the infestation. This decrease is attributed to the general application of soil treatment, mainly with D-D but also with products of the Vapam type, which were officially approved in Algeria in 1960. A decree of September 6, 1954, stipulated that all soils used for nurseries must first be examined by the Plant Protection Service. The decree has since been amended limiting this requirement to horticultural nurseries growing vegetables.

A decree of February 17, 1961, regulates the importation of plants and plant products that might carry the pest.

The National Institute of Agronomical Research is conducting studies of the nematode.

[7] Information contained in this chapter was prepared on the basis of reports of foreign governments, reports of U.S. agricultural attaches, EPPO reports, results of office research, correspondence, and related information.

Argentina

The following summary of the golden nematode situation in Argentina (fig. 54) is based on a translation of a report by Dr. Enrique Brücher (*3*):

"In our discussions with North American and European colleagues on the biological relationship between *Heterodera rostochiensis* and the South American Solanaceae, we have always been of the opinion that the center of origin or natural habitat of the parasite should not be far from regions of a wide genetic and physiological diversification of the generic group *Tuberarium* (the tuber-bearing species of the genus *Solanum*) and from places where we have collected carriers of genes of natural resistance against this nematode.

"As we have explained in a previous preliminary publication (Brücher 1960), it must be supposed that the true origin of this nematode would be South America and, more precisely, the high valleys of the boundary zone between Argentina and Bolivia. All our searches for years in the northern Provinces for the purpose of finding in the soil of the wild tuberous species of *Solanum,* cyst of the golden nematode, were in vain until for the first time, in February 1955, in the high valley of Purmamarca (Province of Jujuy) we observed protuberances on roots of a wild species of *Solanum* which appeared to be caused by the golden nematode.

"We passed years in doubt, until on the occasion of the 'International Expedition of Genocentros, 1958,' we had the opportunity to confirm definitely the findings. We found thus in the soil of Tascal at 3,600 m. alt., in the mountainous part in the north of the Chani Mountains, cysts typical of *Heterodera rostochiensis* on a wild species of *Solanum* (Tuberarium). Some weeks later we discovered other foci of infection in the eastern part of the Department of Tilcara in a valley leading from Abra Remate (4,000 m. high) to Durazno, and another in a valley in the north of the Cerro Sisiler (4.700 m.).

"In both cases the cysts of *Heterodera rostchiensis* were found in humus where *Solanum acaule, S. gourlayi,* and *S. alticolum* were numerous. In the finding at the Valley Durazno there were small patches with *S. vernei* in abundance, also, *S. infundibuliforme, S. acaule, S. alticolum,* and an undetermined species in the environs and, besides, abandoned plantings of native potatoes. The finding at the Valley Durazno was sent for definite confirmation to the Istituut de Nematologia de Holland, our determination being affirmed by the Director, Dr. Oostenbrink, in a letter dated January 24, 1959. We are convinced that with adequate survey and personnel training, many more natural foci in wild species of *Solanum* (Tuberarium) could be discovered in the Provinces of Salta and Jujuy.

"But the proof of the existence of these minute cysts on roots in the soil is a task difficult enough when one is not adequately prepared. Therefore, one must suppose that the distribution of the golden nematode must be much greater in northern Argentina than our casual findings indicate.

"There is not the least doubt that the great potato-growing region of Argentina (south of the province of Buenos Aires) is equally threatened by this enemy of the potato."

Austria

The golden nematode was first found in Austria in 1940 and is known to occur in six of nine Provinces; namely, Vorarlberg, Salzburg, Upper Austria, Lower Austria, Carinthia, and Styria. The extent of distribution of the potato root eelworm is not exactly known because regular soil examinations are carried out only in the seed-potato-producing areas (fig. 55).

Existing provincial plant quarantine legislation provides sufficient legal authority for the adoption of measures to control the golden nematode. To contain the spread of the nematode in Austria, the Federal Institute for Plant Protection has worked out recommendations for growers to follow.

If soil surveys reveal an infestation level No. III (see Appendix II), a minimum of 5 years should elapse and the field should again be soil sampled before potatoes are planted. At level No. IV there is an added requirement that the entire potato crop of the affected farm be examined each year until the outbreak is wiped out. At level No. V the farmer should be made to discontinue potato production until the outbreak has been greatly reduced. In home gardens and on small plots or in mountain locations where rotation or chemical control is impracticable, resistant potato varieties are recommended. In areas devoted to seed production with infestation levels No. III and IV and where the level is No. V, the use of suitable nematocides, preferably in combination with the single-time use of nematode-resistant potato varieties, is recommended.

The resistant potato variety Antinema and the varieties Apis, Amelio, and Amaryl are being grown in Austria.

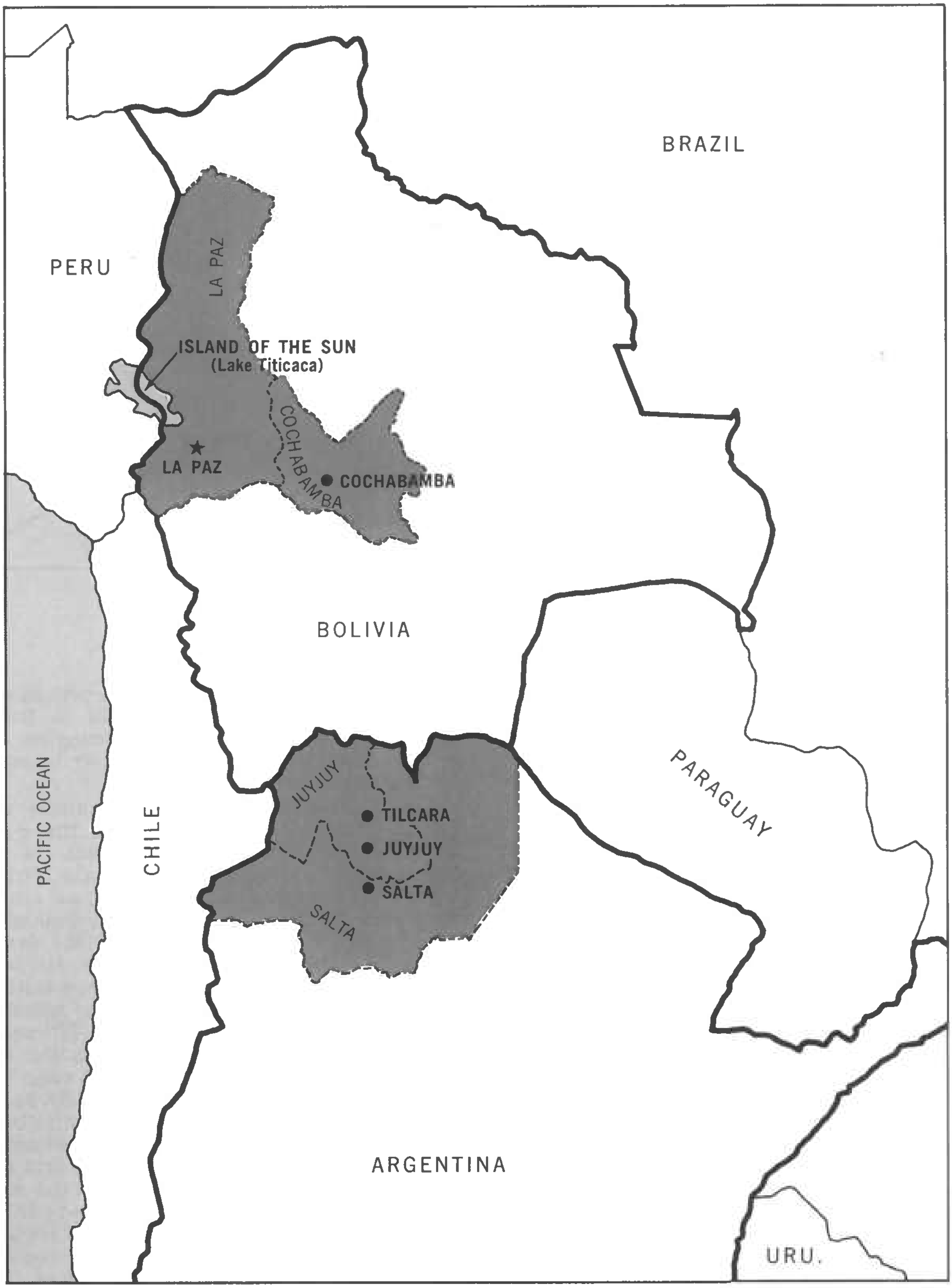

FIGURE 54.—Infested areas in Argentina and Bolivia.

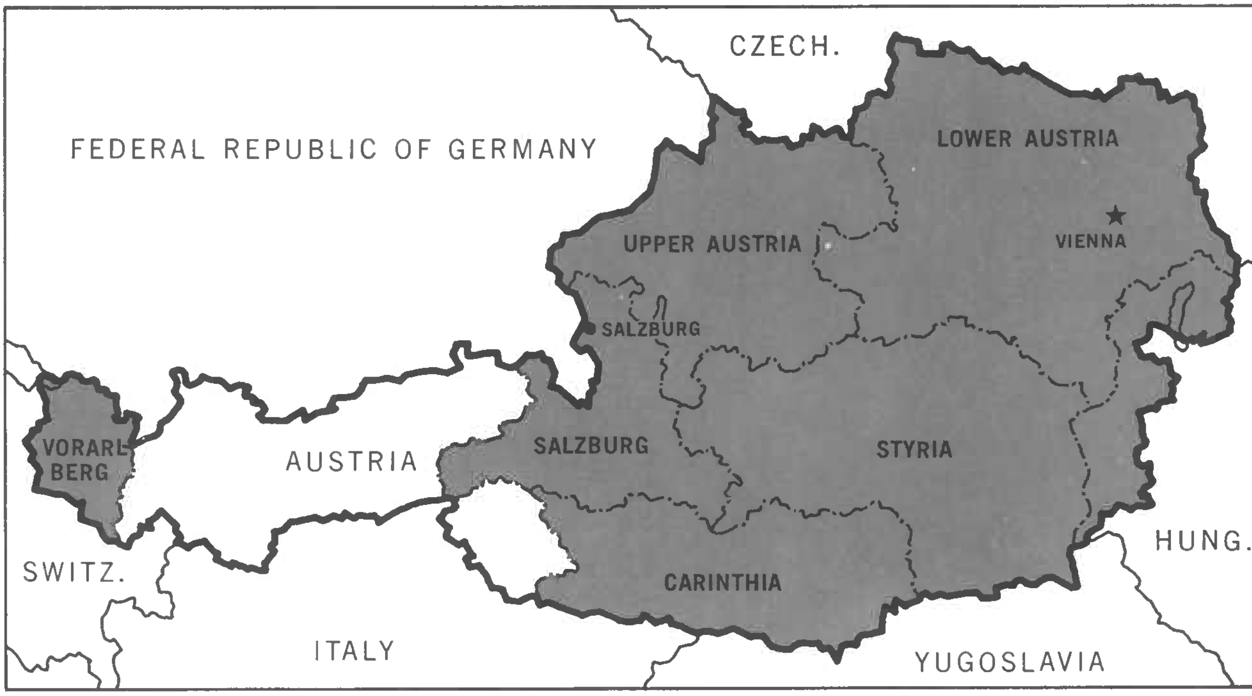

FIGURE 55.—Infested provinces in Austria.

Belgium

The golden nematode was first found in Belgium in 1949. Belgium prohibits growing potatoes and tomatoes on the same land more often than once every 3 years. On infested properties the law prohibits the growing of potato, tomato, and other vegetable plants for transplanting for a period of 5 years. This period can, however, be lengthened or shortened depending on circumstances, such as viable cyst count. The law requires that early potatoes be harvested no later than June 20.

On the Belgium coast where commercial potatoes are grown, the Government has a soil treatment program using D-D at the rate of approximately 63.4 gallons per acre. The Plant Protection Service has a systematic soil sampling survey throughout the country. All samples are processed at Ghent. Studies are underway to determine whether resistance-breaking races occur.

Bolivia

The following description of the golden nematode situation in Bolivia was summarized from a report by Frank H. Bell and B. Alandia Segundo (*1*).

During the period 1952–54, observations were made on the diseases of potatoes in Bolivia that should be of interest to pathologists elsewhere, especially since the area may be one of the ancestral homes of the potato.

One of the more interesting organisms noted for the first time in Bolivia was the golden nematode, *Heterodera rostochiensis*. It was found to be widespread in the Lake Titicaca region of northwestern Bolivia, at an altitude of 12,600 to 13,000 feet (fig. 54). One of the sites where it was noted was on the famous "Island of the Sun" of the prehistoric Incas. It was also found in the Tunari range (altitude 11,000 feet) near Cochabamba. This latter site is 200 miles southwest of Lake Titicaca in mountains that are separated from the main Bolivian Altiplano. The widespread occurrence of this nematode in long cultivated, heavily populated regions of Bolivia substantiates the theory of Ing. de Segura of Peru, where the nematode was noted in 1952 for the first time, that this nematode is indigenous to the Andes and was probably carried from there to Europe and then to the United States. The root-knot nematode, *Meloidogyne* sp., has been found on potatoes in the sandy soils of the Island of the Sun, and in the highlands east of the Cochabamba Valley.

Canada

The golden nematode was first discovered in Canada in the Province of Newfoundland in October 1962, in the community of Manuels on Conception Bay some 14 miles west of the city of St. Johns. The discovery of the pest was not entirely unexpected because no import restrictions were maintained by the colony until 1949, when Newfoundland became a Province of Canada. Potatoes and other vegetables were imported from Great Britain when the necessity arose, and it is possible that the nematode was introduced many years ago.

The importation of potatoes into Canada from Newfoundland has been prohibited since 1910 because of potato wart. Following the confederation with Canada, the regulations under the Destructive Insect Pest Act were amended to continue the prohibition of the movement of potatoes, soil, plants with soil, used bags, and other items, and to prohibit their export to other countries.

The Canada Department of Agriculture's Plant Protection Division, under the authority of the Destructive Insect and Pest Act and the Destructive Insect and Pest Regulations, has broad power to prohibit or restrict the importation of plants with soils or packing materials, containers, machinery, implements, vehicles, and other carriers containing soil or to which soil may adhere. This applies to all countries except the continental United States unless plants with soils have been thoroughly washed or otherwise treated immediately before movement into Canada and unless the importation is accompanied by an affidavit or declaration to that effect.

Canada has been particularly alert for the presence of the golden nematode in the country because of the importance of seed-potato exports. Canada produces annually about 70,000 acres of seed potatoes on nearly 10,000 fields in nine Provinces. A random survey, started in 1959, has been conducted throughout the seed-producing areas.

On June 16, 1965, a potato farmer on Vancouver Island, Saanich Peninsula, near the city of Victoria, British Columbia, brought to the Saanich Peninsula Agricultural Experiment Station a potato plant with soil for examination by the pathologist. The plant and soil were examined by W. R. Orchard and N. Waseem and found to contain a large number of golden nematodes in various stages of development. Specimens were sent to Ottawa for confirmation, which came on June 21.

The infested property belonged to a farmer who had formerly grown bulbs. He had imported bulbs from Europe and had grown the last crop of bulbs on the infested property in 1938. Between 1938 and 1950 he grew various crops and since 1950 he had continuously grown potatoes on the field (fig. 56).

The Canada Department of Agriculture's Plant Protection Division took immediate steps to regulate the movement of crop plants and commodities that might carry the nematode out of the area. In consultation with the author of this handbook, a program to combat the nematode was developed. A laboratory was established, surveys instituted, and quarantine regulations established.

By 1966, surveys conducted throughout the Province of British Columbia showed that the golden nematode was confined to a small area on the Saanich Peninsula. Cysts of the golden nematode have been found on approximately 150 acres.

All infested lands are removed from production and fumigated with dichloropropene-dichloropropane at the rate of 50 imperial gallons per acre. At least two applications are given each field. In addition, some 300 acres exposed to infestation have been removed from potato production and fumigated. The Canadian Government compensates growers for their losses.

Canary Islands

According to a report by R. Chamberlain, University of Belfast, and Iuan Valladares Barbuxano, they discovered the golden nematode in La Victoria de Acentejo and in other districts in Tenerife, Canary Islands, on December 27, 1960 (*6*). According to Chamberlain, the discovery was made at latitude 28° 25′ north. This appears to be the most southern occurrence as yet recorded of *H. rostochiensis* in the Old World. (See Spain.)

Chile

In October 1966, the Minister of Agriculture, Santiago, Chile, telephoned me and advised that a shipment of 3,500 metric tons of Irish potatoes from Europe were in port and had been found to be contaminated with the golden nematode. Safeguards were discussed and agreed upon for the safe disposition of the potatoes. All the potatoes, except a few bags, were washed and sold for consumption in metropolitan areas. The unwashed potatoes were later moved to a farm. In December 1967, I was advised that representatives of the De-

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FIGURE 56.—The original infested field on Vancouver Island, British Columbia. The property had previously grown bulbs imported from Europe. The farmer first noted stunted potato plants in 1964. When this photograph was made by the author on June 23, 1965, the entire field showed evidence of damage.

partment of Defensa Agricola had inspected a farm in an isolated valley in Aconcagua Province, where the potatoes had been used for seed, and had confirmed the presence of the golden nematode.

Czechoslovakia

The golden nematode was first recorded in Czechoslovakia in 1954.

Infestation in Czechoslovakia consists mainly of isolated pockets in private gardens where crop rotation is not properly observed. The intensity of attacks is low. Infestations occur in Bohemia and northern Moravia. The Government regulates growing of potatoes and other host crops on infested land. This regulation prohibits growing of other host crops on infested land for 5 to 7 years, requires crop rotation, and severely restricts the utilization of potatoes grown in infested communes. Imported potatoes are carefully inspected. The Quarantine and Plant Protection Service enforces Decree No. 1, 1959. Research is being conducted to detect biotypes of the nematode.

Denmark

The golden nematode has been known to exist in Denmark since 1928. The State Plant Pathology Institute examines soil samples for cysts of the golden nematode in connection with the certification of seed potatoes and other plant products for export. Sampling in potato fields and examination of soil samples for cysts comply with the approved international rules.

Only a few attacks of the nematode are found annually in cultivated agricultural land. Most of the infestations observed from 1964 to 1966 were in the northern part of Jutland (fig. 57).

In certain contaminated areas, mostly gardens, series of samples have been investigated to determine the degree of infestation and stop the spread of the nematode to adjoining seed-potato fields. Growing of potatoes on infested land is prohibited for a number of years under regulations of the State Plant Protection Service.

Potato growing has been prohibited for many years in nurseries. Most nurseries have been found free of the nematode. Areas where the nematode has been found are under frequent observation and production is controlled. Analysis of samples from these areas are the basis for deciding whether potatoes and nursery plants may be grown there.

Altogether, the Government's Plant Protection Service has recorded infestations in 25 counties, as follows:

	No. of infestations
Private gardens	106
Commercial cultivated agricultural land	160
Commercial horticulture and gardening	37

Under systematic investigations 64 agricultural holdings, where the Government's Plant Protection Service had recorded potato root nematode from 1956 to 1964, were investigated to determine if the pest had spread to other fields. The purpose of this investigation was to test the Protection Service's usual practice of recording only the affected areas on individual holdings. The investigation showed that 61 percent of the holdings where the nematode had been recorded in one part had newly infested parts.

In Denmark the work of producing varieties resistant to the golden nematode has been very intense, and it is expected that commercial varieties will be available for growers on a limited scale by 1969. These investigations are conducted at the Potato Improvement Research Station in Vandel. The testing is done at the State Plant Pathology Institute at Lyngby.

Investigations over the past 3 years (1964–

FIGURE 57.—Occurrence of the golden nematode on potato farms in Denmark.

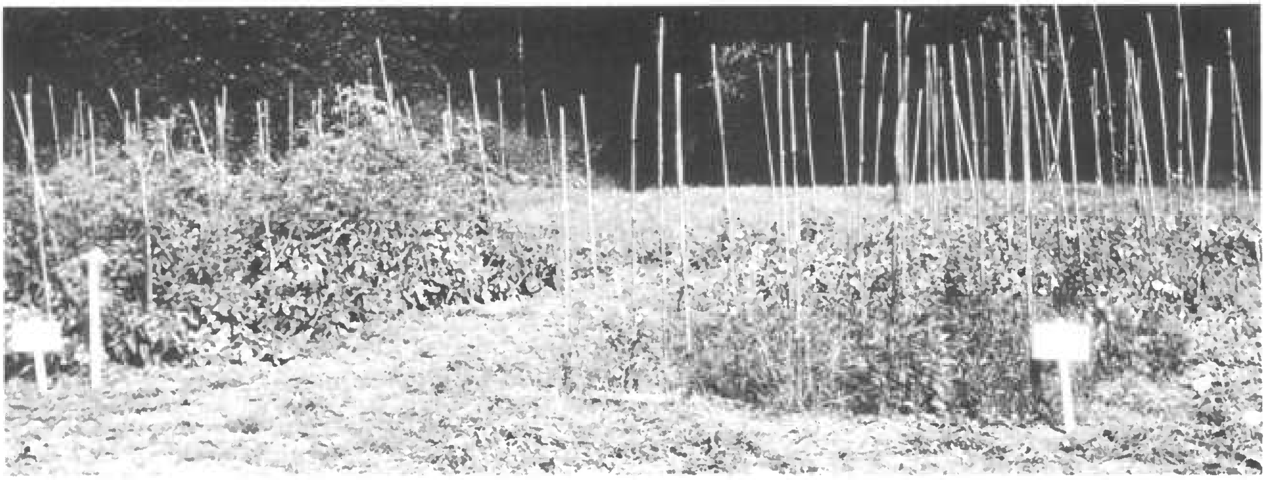

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FIGURE 58.—Test plots showing the effects of golden nematode on tomatoes at Imperial College field station, Sunninghill, Ascot Burkes, England.

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FIGURE 59.—A potato field in England, showing heavy damage caused by golden nematode. [British Crown Copyright; reproduced by permission.]

66) have been carried out to see if resistance-breaking biotypes can be found. None have been found to date.

The use of soil fumigants is primarily on the Amager island southeast of Copenhagen where there is a heavy concentration of vegetable farming. The nematocide D-D is used at the rates of 45 to 60 cubic centimeters per square meter for fumigating soil in greenhouses. In cultivated fields 400 to 500 liters per hectare (about 2½ acres) of D-D is used. The cost of fumigating one hectare in 1966 was about 1,500 kroner ($210).

The Government's Agriculture Advisory Service strongly recommends to farmers that do not have infested land a sound rotation program of at least 2 to 3 years for potatoes.

England and Wales

The golden nematode in England and Wales was confined to Yorkshire in 1917, but it had probably been present for 10 to 15 years before that time. It is also reported that the nematode was causing damage to tomatoes (fig. 58) in Yorkshire as early as 1928.

According to Southey (*38 pp. 171, 173, 174*), the nematode is well-distributed in the ware-potato districts of the country. Because of the demand for potatoes during World Wars I and II, the problem was compounded. Southey reports that following World War II the potato acreage rose nearly to the one million mark, and complete or partial crop failures were frequent. In 1949, a conservative estimate was made by the Ministry of Agriculture that losses caused by the golden nematode were about 2 million pounds sterling, or equivalent to about $10 annually on each acre of potatoes (fig. 59).

Despite the situation, England has been fortunate in that the golden nematode is rare in the main seed-producing areas (fig. 60). Surveys are conducted by the Ministry of Agriculture as an advisory service to growers. The Ministry of Agriculture, through the Extension Service, has advised growers on the importance of long rotations, especially in areas where the nematode populations are light. After commercial damage appears in a field, the Ministry of Agriculture advises the farmer to leave it out of production for 6 years or longer to be sure that no economic damage to crops will occur. The Ministry of Agriculture then recommends potato producing on a 1 year out of 5 rotation.

FIGURE 60.—Distribution of the golden nematode on commercial potatoes in England and Wales.

Faeroe Islands

The first report of the golden nematode in the Faeroe Islands was in 1951 when K. Lindhardt (*24*) examined 15 soil samples and found they were all infested. In 1964, another survey was made of the Islands, and 19 of 93 samples collected were found to contain cysts.

The golden nematode may have existed in the Islands before 1940, but it is more likely that this pest was introduced from Great Britain during World War II on supplies for troops. Several infested soil samples from the Islands were found to contain an aggressive biotype that attacks varieties of potatoes containing resistance of *Solanum tuberosum* subspecies *andigena*. Aggressive biotypes are not uncommon in Scotland and some parts of England, but they have not been detected in Denmark.

Although the Ministry of Agriculture of Denmark issues regulatory orders to control the golden nematode, plant diseases, and insect pests, the orders do not apply to the Faeroe Islands.

Potatoes are produced on about 150 hectares (375 acres). Since soil suitable for growing potatoes is limited, some fields have been in potato production for more than 100 years.

Finland

The golden nematode was first reported in Finland in 1946. Nematode surveys are systematically conducted in the country by Tuhoelaintutkimuslaitos, Tikkurila. Infestations are confined to the southern part of the country and do not extend beyond the region of Tampere (61°40′ N.) (fig. 61).

Finnish Government regulations prohibit the growing of potatoes on infested land from 3 to 5 years. Resistant varieties are available. The most common variety in use is "Antinema." Approximately 2,500 kilograms (5,511 pounds) of this variety have been distributed to farmers.

FIGURE 61.—Infested areas in Finland.

Research is being conducted on the golden nematode problem. Biotypes A, B, C, and D have been discovered.

France

The golden nematode was first reported in France in 1947.

A Ministerial Order, dated November 15, 1963, and published in the Official Gazette of November 27, 1963, page 10597, sets forth the requirements for control of the potato root eelworm throughout the country. The main provisions are restrictive measures, including systematic soil sampling of areas surrounding fields in which the pest has been recorded by the Plant Protection Service; prohibition of the growing of seed potatoes on infested soil for 5 years; if infestation exceeds a prescribed level, prohibition also of growing ware potatoes, tomatoes, and all crops for transplanting; prolongation of prohibition for further 3-year periods until samples confirm absence of pest; and directives for the use of underground parts of all crops growing or ready for harvesting in the zones in which restrictions apply.

The intensity of the attack of the nematode varies greatly in different regions. Severe attacks have not occurred in recent years because soil examination is made of fields and when infestations are found to exceed an acceptable level the growing of host plants is prohibited for 5 years. Resistant varieties of host plants are also being tried. In fields where infestation is particularly heavy, total prohibition of host plants is necessary. A race of golden nematode that broke the resistance of the potato variety Antinema has been found in Saint Malo.

Germany (East)

The golden nematode is widely distributed in East Germany. The infestations are most numerous on sandy soil, and for economic reasons potatoes have been grown too frequently. Most communes of the country are infested. In some areas between 2 and 3 percent of the total agricultural area is infested. However, in the northern area (Mecklenburg and Brandenburg) the averages occasionally are as high as 8 percent of the agricultural area.

East Germany also uses resistant potato varieties. Regulations are enforced on crop rotation and the movement of infested commodities. Soil examination of fields is made to determine when infestations exceed an acceptable level, whereupon the growing of host plants is prohibited for 5 years. Rotation of potatoes and tomatoes is compulsory. Through these measures, intensity of attack is kept at low levels.

Rules governing marketing are contained in a decree published June 29, 1963, in the *Gesetzblatt II*.

Germany (West)

It is from Germany that we first learned about the potato nematode problem. (See History and Origin of the Golden Nematode.)

There are no official figures on the extent of distribution within the German Federal Republic, although it is known that the potato nematode occurs in all States. After a considerable postwar increase in nematode incidence, the infestation intensity decreased especially in recent years mainly because an increase in the standard of living (and associated decline in demand) had caused a decrease in potato cultivation.

The basic legislation on potato nematode control in the Federal Republic is (a) the Ordinance of July 20, 1956, Prevention of Occurrence and Control of Potato Nematodes, and (b) Ordinance Amending the Ordinance on Prevention of Occurrence and Control of Potato Nematodes of July 26, 1961.

According to these ordinances, the production of potatoes and tomatoes as well as the construction of dirt storage pits is, on principle, forbidden in infested areas until the Plant Protection Service has declared the areas to be free of infestation (fig. 62). On the basis of these ordinances, the States have established implementing ordinances, which consider any special local conditions in their areas.

The breeding of nematode-resistant varieties of potatoes is being pursued with great vigor. The Federal Variety Agency (Bundessortenamt) has acknowledged that three varieties are resistant against nematodes: Antinema, Apis, Cobra.

In several localities of the Federal Republic there occurs the resistance-immune biotype B of the potato nematode. It is expected that further resistance-immune biotypes will be discovered.

As a matter of principle, the Government does not interfere with crop rotation on noninfested areas. Farmers are advised, however, to plant potatoes and other nematode host plants only every third year. If an area is considered to be endangered with infestation, the authorities may order that potatoes can be planted only every third year.

FIGURE 62.—Poster used by West German extension service to alert farmers to the golden nematode problem.

The growing of potatoes on infested land is basically forbidden. Upon application, the Government may grant exemptions—for example, for the growing of resistant varieties; for noninfested parts of fields, provided these parts or neighboring fields are not endangered; for scientific and breeding purposes, provided this does not endanger nematode control.

The Plant Protection Offices inspect their areas for the occurrence of potato nematodes and other pests. All enterprises producing for export (horticultural enterprises, tree nurseries) are officially inspected periodically for noninfestation; for example, in North Rhine-Westphalia the total area is inspected every 4 years and the ground storage places every 2 years. Similar regulations exist in the other States.

Before seed potatoes can be grown, an official inspector must declare the area free from infestation. In addition, random sample inspections for nematodes are carried out in areas considered to be in danger of infestation.

Greece

The golden nematode was found in Greece for the first time in 1951 in the mountainous area of Parnon Arkadia (*2*).

The golden nematode was found in 11 locations administratively belonging to the prefectures of Arkadia, Messinia, Boeotia, Serres, Larisa, Chalkidiki, and the Cyclades islands (Paros, Naxos) after research was carried out by the Benachi Phytopathological Institute. The Ministry of Agriculture has since reported six locations belonging to the prefectures of Elis, Lakonia, Imathia, Lasythion, and the island of Aegina.

The above areas are not entirely infested by the nematode but are limited to spots of up to 500 square meters. Infested areas where potatoes are grown are estimated to be about 30,000 to 50,000 stremmas (7,410 to 12,350 acres). Total area of potato production is about 480,000 stremmas (118,560 acres).

The Ministry of Agriculture recommends to the growers the use of nematocides, which lately are being used on a growing scale. Furthermore, where an infestation has been observed in seed-potato-producing centers, the Ministry of Agriculture requires compulsory washing of seed potatoes with special equipment.

Generally, to control the spread of the nematode and protect the potato crop, a rotation is recommended. Relevant instructions have been issued by the appropriate service of the Ministry of Agriculture.

Nematocides recommended for the control of the golden nematode in Greece are D-D soil fumigant at the rate of 100 to 200 kilograms (220 to 441 pounds) per acre and ethylene dibromide at the rate of 40 to 100 kilograms (88 to 220 pounds) per acre.

There are no resistant potato varieties.

The cultivation of potatoes in infested areas is not legally prohibited, but the Ministry strongly recommends that such fields not be used for potatoes.

Seed-potato-producing centers are immediately abolished upon the finding of the nematode.

Guernsey

The golden nematode was first reported in Guernsey in 1952.

Infestations are now fairly widespread throughout the island of Guernsey. Any apparently new infestations usually indicate a sudden local increase in the pest population as a result of cropping potatoes 2 or more years in succession. Some control measures using D-D are proving highly successful.

Iceland

The golden nematode was first detected in Iceland in 1953. Its presence is limited to a small area in the Westman Islands, and in two small villages on the southwest coast of Iceland—Eyrarbakki and Stokkseyri.

During August and September, roots of potato plants are examined to determine the extent of the infestations. Technical agricultural experts are available in each of the counties, and they endeavor to keep informed on agricultural developments. Resistant potato varieties are not considered suitable for Icelandic soil conditions, and chemical fumigants are not used because they are too expensive. Resistance-breaking biotypes are not known to be present.

Although the Government has no special regulations concerning the rotation of potatoes on land not known to be infested, it advises producers of the desirability of rotating crops. Growers are also advised by the Government officials not to plant on infested fields.

India

The golden nematode was first identified in India in 1961 and is thought to be restricted to certain areas in Nilgiri Hills of Madras State (fig. 63). Intensive field surveys to determine the distribution of the golden nematode in Madras State have been in progress since 1963. The first round of surveys was expected to be completed by June 1967. A total of 946 acres out of 24,000 acres of potato-growing area has been found to be infested.

Research on the problem is in progress under the direction of the Indian Council of Agricultural Research at Ootacamund (Nilgiri Hills, Madras) in collaboration with the Central Potato Research Institute. Research includes search for biotypes, experiments with resistant potato varieties, testing of soil fumigants, and a study of the effect of 1-, 2-, 3-, and 4-year rotation of nonhost crops.

The question of imposing a domestic quarantine against the golden nematode in the infested area is under consideration. The growing of potatoes on infested land is not recommended. Under the Destructive Insect and Pest Act, 1914, the importation of potatoes is pro-

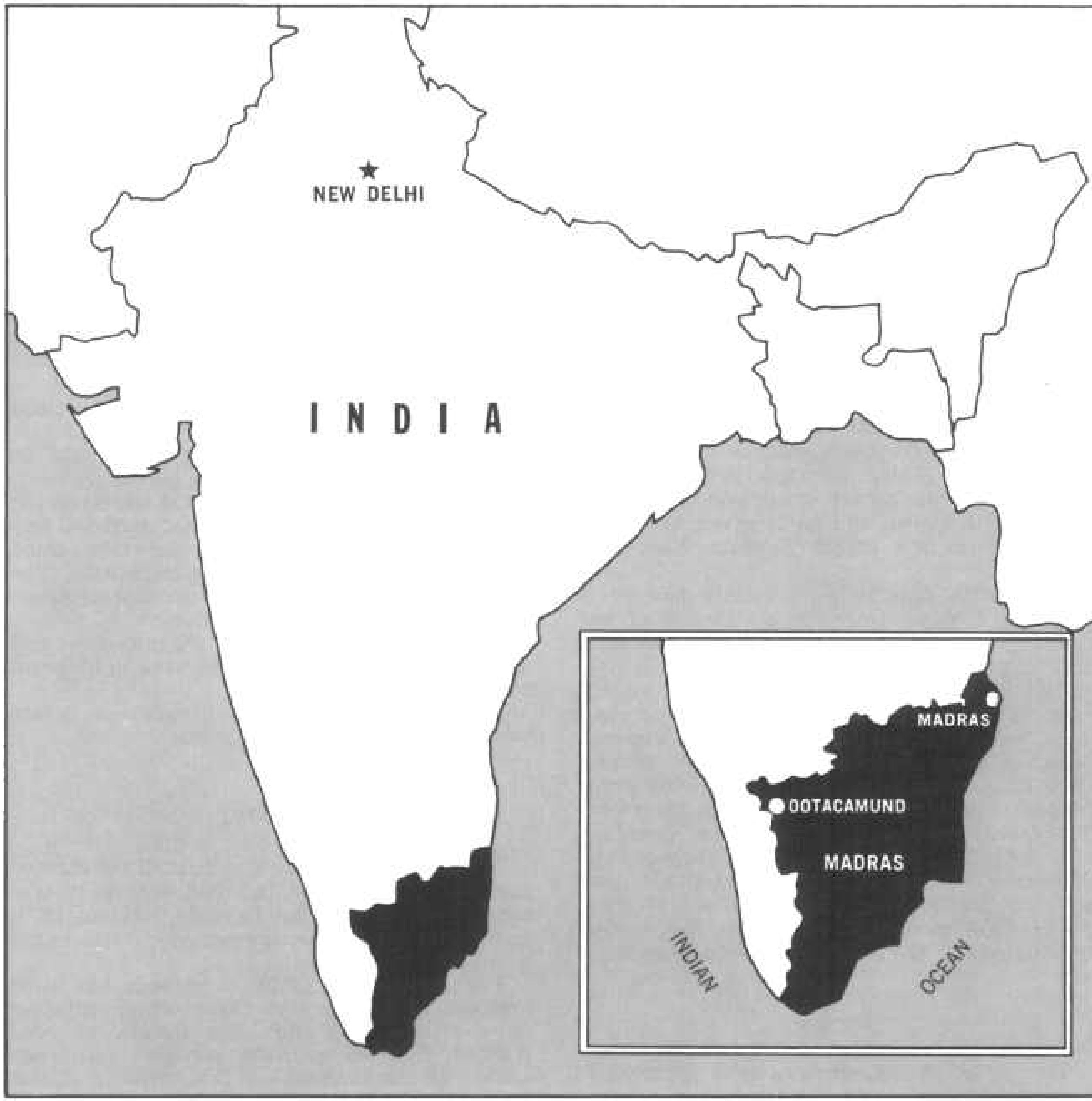

FIGURE 63.—Infested areas in India.

hibited except in small quantities for research or scientific purposes.

Ireland

Distribution of the golden nematode in Ireland appears to be limited although the nematode has been known to be present since 1922. Infestation occurs mainly in pockets of land in districts that were once congested (bogland and hillsides), where a rotation of crops was not feasible under the land tenure system of the 19th century. Most of this land is no longer cultivated. Golden nematode also is frequently found in urban and suburban gardens following poor rotational practices.

The Destructive Insects and Pests (Consolidation) Act of 1958 sets forth regulations concerning the golden nematode. This act em-powers the Minister of Agriculture and Fisheries to issue various orders. One of these is the Potato Root Eelworm Order of 1951.

Potato varieties resistant to the golden nematode are available in Ireland only for research purposes. No such varieties are available commercially.

Chemical fumigants are not used against the golden nematode on outdoor crops grown in Ireland. However, Dazomet (methyl-iso-thiocyanate) is used to control the golden nematode in tomatoes grown under glass.

Farmland found to be infested with golden nematode must be sown with grass immediately in accordance with the Potato Root Eelworm Order. The Department of Agriculture and Fisheries does not consider it practical to extend this requirement to urban garden plots because of the frequent changes in occupiers. But when the golden nematode is found in urban gardens, the owner is advised to sow the garden with grass, and he is given a copy of the Department's leaflet "Potato Root Eelworm."

Surveys to date indicate mostly biotype A occurs in Ireland. Only one population of biotype B has been found. No other biotypes have been found.

Ireland has no legislation controlling the rotation of crops. Rotation of seed potatoes is controlled, however, under the Government's Certified Seed Potato Scheme, and several Irish companies using potatoes for industrial purposes include rotation clauses in their contracts with growers. The Irish Sugar Company uses potatoes in its potato flake factory, and Ceimici Teoranta (Chemicals Limited) uses potatoes for making glucose. Both of these Government-sponsored companies have rotation clauses in their contracts with growers.

Israel

The golden nematode was first detected in Israel in 1957. A minor infestation was found in the Raanana region, Petach-Tikva subdistrict (15 miles north of Tel Aviv) all within a radius of 3 miles.

The Plant Protection Service of the Ministry of Agriculture conducts systematic surveys of all potato fields in the Raanana region. So far, it has been unnecessary to apply Government regulation. The Extension Service of the Ministry of Agriculture recommends one potato crop in 3 years in the region affected by the nematode. As a rule, farmers comply with the advice given by the Extension Service officer in an effort to control pests of this nature.

There are no resistant potato varieties available and no resistance-breaking biotypes are known. Some experimental work has been done with soil fumigants using ethylene dibromide at the rate of 60 liters to the acre (15.85 gallons).

Italy

The occurrence of the golden nematode in Italy was first reported in 1962. According to the Ministry of Agriculture, infestations are found mainly in the Naples area where early potatoes are grown. Some scientists think that the infested area is much more widespread.

The Naples area has maintained fairly good yields. This may be related to the use of cow manure as a fertilizer, which is thought to inhibit the development of the nematode.

At a potato conference in 1964, Government control measures were petitioned without success. Imported seed potatoes, however, must come from areas free of the nematode. The Government does offer advice on control measures recommending crop rotation.

Fields in the infested area are numerous and small. The potato crop in this area is of great economic importance.

Research is underway on resistant potato varieties and chemical fumigants.

Jersey

The golden nematode was first discovered on the island of Jersey in 1938 where it was causing serious damage to early potatoes (*37*). Later that same year, the nematode was found in a field of tomatoes.

The seriousness of the nematode has been demonstrated in a few cases where potatoes have yielded less than the weight of seed planted. Tomato growers are also concerned about the seriousness of the problem. Cases have been reported where yields of tomatoes have been reduced from 15 tons an acre to less than 2 tons. Soil samples are examined for growers on an advisory basis. In general, more than 50 percent of the samples examined have measurable contamination.

Soil fumigation using D-D, methyl bromide, and Vapam is in use. Under a law that came into force in 1962, approved materials for potato root eelworm control were subsidized. The subsidies being granted were for soil sampling or crop examination, or both, which show whether the pest populations have reached the level sufficient to cause crop damage.

Luxembourg

The golden nematode was found in Luxembourg in 1955. Potato-producing areas are surveyed for the presence of the nematode. However, only 20 hectares (50 acres) are known to be infested.

The soil fumigants Vapam and Nemacur have been tested as control measures for the nematode. Growers, if they choose to do so, may import resistant varieties of potatoes.

Although there are no specific Government regulations against the golden nematode at this time, the Government will implement regulations developed by the European Economic Council.

Netherlands

The golden nematode was first reported in Holland in 1941. Regulatory action was taken shortly after that to restrict and control the pest. These regulations were amended in 1947 and again in 1949. A law was passed to prohibit the growing of potatoes and transplants in infested land and to set up special precautions for the distribution of infested material. Growing potatoes on noninfested land more often than once every 3 years is also prohibited. This regulation alone has had a direct effect on the farming practices of the country.

These regulations have prevented the buildup of the nematode and protected the country's export of many agricultural commodities.

Protective crop rotation is strictly enforced and has the support of farm organizations. Potatoes grown against regulations are destroyed. Bulbs and perennials cannot be grown on land where there is any danger of spreading the golden nematode. Potatoes are prohibited from being grown in the bulb-growing districts of Holland. The towns, communities, and boundaries of areas where growing potatoes is prohibited are specifically outlined in Government regulations.

The growing of resistant varieties of potatoes is a specific part of the Government regulations to combat the golden nematode. Each year the Government designates those parts of infested districts or properties that may be planted to varieties resistant to the golden nematode. In 1966, a total of 3,800 hectares (9,500 acres) was planted to resistant potato varieties. Holland's best varieties for industrial potato are Saturna and Prevalent. The best tablestock potato is Amaryl.

Early potatoes must be harvested before June 26, except in north Holland where the harvesting date is designated as July 6. Harvesting dates may vary from year to year, depending on growing conditions. Potato growers who plant early varieties are permitted under the law to grow potatoes on the same land every other year.

Potatoes and tomatoes are prohibited from being grown in the nursery stock growing area of Boskoop.

The resistant potato varieties that are now available to growers have a resistance to the more common biotype A of the pest only. Growing these varieties is not permitted in fields that are infested with other biotypes. Good progress has been made with the development of varieties with resistance to biotypes other than A. These varieties are also expected to be available commercially within a few years.

Holland has an extensive research program at Wageningen to investigate many aspects of the nematode control problem including biological and chemical control, potato breeding studies for the development of resistant varieties, resistance-breaking biotypes, and other research.

Northern Ireland

The golden nematode was found for the first time in Northern Ireland in 1933 on a potato crop in a garden near Belfast.

Regulations relating to the golden nematode were first introduced in 1945, and the various modifying enactments that followed have been consolidated into a single measure, the Potato Root Eelworm Order, Northern Ireland, 1960. Under the terms of this order, the golden nematode is a "notifiable" pest, and wide regulatory powers are vested in the Ministry of Agriculture for the enforcement of the order by such means as necessary.

A systematic survey has been in operation in Northern Ireland for 20 years. Upon discovery of the golden nematode on any land, certain prohibitions are enforced, such as (a) the removal for planting purposes of any potatoes, tomato plants, or other propagating material; the disposal of such plant or plant products from infested land will be in accordance with directions from the Ministry of Agriculture; (b) the removal of infested soil from any premises whether loose or adhering to the roots of plants, implements, or other articles; (c) the planting of infested property to potatoes, tomatoes, or plant propagating material. These restrictions remain in force until withdrawn by the Ministry of Agriculture. Since the first notices of infestation were issued in 1945, there have been no instances where resumption of potato growing has been permitted or where any of the other requirements have been released.

Glasshouses in which infestations are found are permitted to resume normal culture of tomatoes or other glasshouse plants provided such establishment can be freed of infestation to the satisfaction of the Ministry of Agriculture. Under such situations, steam sterilization of soil and other cleanup measures are satisfactory to eradicate infestations.

Field infestations of commercial potatoes are for the most part confined to five districts, each of which is designated by the Ministry of Agriculture as a "scheduled area." These areas embrace the infested property and a wide peripheral zone. Within these areas the provisions of the potato root eelworm order apply.

FIGURE 64.—Infested areas in Norway.

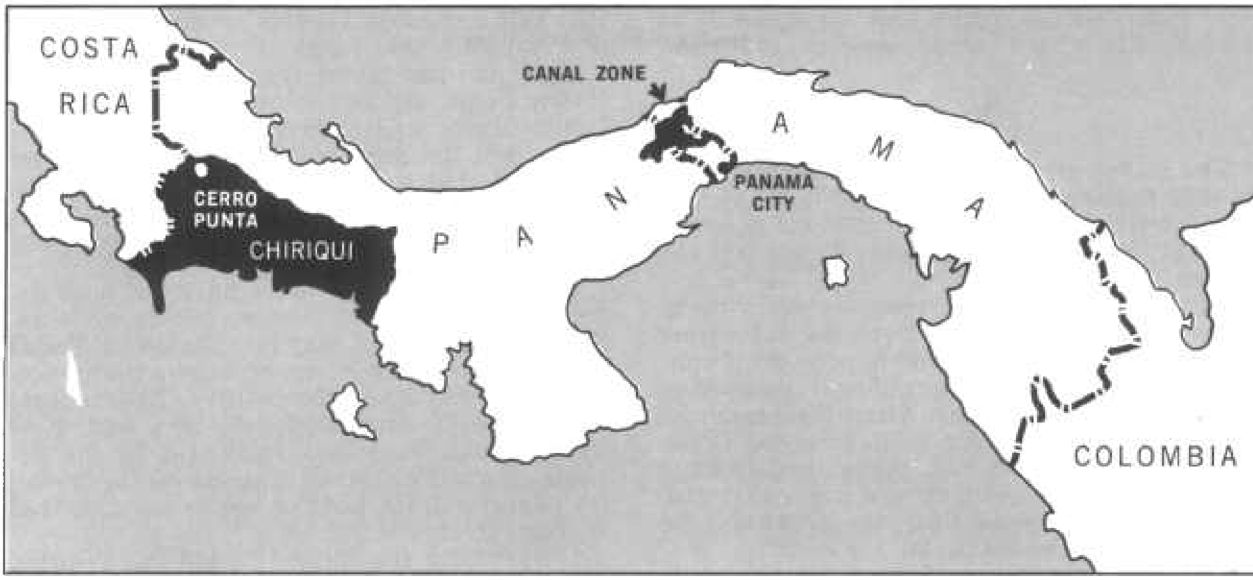

FIGURE 65.—Infested areas in Panama.

In addition, special cropping restrictions require that potatoes shall not be planted on any *noninfested* land in the scheduled area more often than twice in any 8 years.

Norway

The golden nematode was first found in Norway in 1956. The infested farms are located in the coastal counties of Aust-Agder, Vest-Agder, and Rogaland (fig. 64).

The Norwegian Plant Protection Institute, Norwegian Ministry of Agriculture, has issued regulations concerning the control of golden nematode. Regulations include the following: Tractors that might have infested soil must be thoroughly cleaned and washed; the sale of seed potatoes and other plant material from infested areas is prohibited; and the growing of potatoes in infested areas is also prohibited. Exceptions may be made, however, to the last regulation under certain conditions and then only for the growing of potatoes every fourth year. The Norwegian Government's regulations concerning this pest are based on recommendations of EPPO, of which Norway is a member.

The Norwegian Plant Protection Institute, Norwegian Agricultural College, Vollebekk, has developed two resistant potato varieties.

Nationwide surveys for the nematode are being conducted. So far, the southwest, southern, and eastern parts have been covered by this survey.

One resistance-breaking biotype B has been found on one farm. Investigations on resistance-breaking biotypes are continuing.

As a protective measure, the Government strongly recommends to growers that they rotate potatoes on land not known to be infested.

Panama

The golden nematode was discovered in Panama in August 1967 following damage to a potato crop. The infestation is located in Cerro Punta, Chiriqui (fig. 65), according to Dr. Rodrigo Tarte, University of Panama.

The main varieties of potatoes grown in the country are Alpha, Red Pontiac, and Urgenta. Farmers have customarily obtained their seed potatoes from European sources.

Dr. Tarte has organized a survey which is being conducted throughout the potato-growing regions of the country. On October 26, 1967, Mr. Jack E. Lipes, FAO Agricultural Officer, El Salvador, notified the Plant Quarantine Division, ARS, USDA, of the occurrences of the infestation and indicated that OIRSA (Organismo Internacional Regional De Sanidad Agropecuria) was considering placing a quarantine on Panama because of the nematode. Mr. Lipes reported that swollen females were found on the roots of potatoes, and he sent a vial of specimens to the USDA. Dr. A. Morgan Golden confirmed that the specimens were *H. rostochiensis*.

This is the first infestation of the golden nematode recorded from Central America. Officials from OIRSA report that surveys will be conducted in other Central American countries.

Peru

The golden nematode was discovered in Peru in 1952 following United States Plant Quarantine interception of the pest at ports of entry in 1951. (See "History and Origin of the Golden Nematode.")

Potato culture in Peru, represented by many native varieties, including *Solanum tuberosum* and *andigena* subspecies and improved hybrids, constitutes the main agricultural occupation along the mountain range from the border of the Republic of Ecuador to Bolivia and Chile. It is a vast zone in which approximately 200,000 hectares (500,000 acres) are cultivated, excluding the regions near the ocean in the Central Coast Departments.

The economic value of the potato crop is surpassed only by sugarcane and cotton production. These crops are planted in areas near the ocean and within a few inter-Andean valleys. In the mountain zones the potato crop is largely affected by the endemic plague represented by *Heterodera rostochiensis.*

The species *Solanum* X *curtilobum* and *Solanum* X *juzepczukii* (sour potato type) are immune to golden nematode. These are cultivated at altitudes of 4,000 meters.

Ing. Alberto Martin Ravines, of the Agrarian Experimental Station of La Molina, has been making a study of the golden nematode situation in Peru under United States funds provided by Public Law 480. Ing. Martin reports that most of the cultivated area in the Andean region between 2,300 and 4,000 meters above sea level is affected. The greatest infestation has been found at altitudes from 3,000 to 4,000 meters.

Poland

The golden nematode was first identified in Poland (1967 boundaries) in 1946, although it was known to have existed in the eastern part of prewar Germany (now Poland's western Provinces).

Poland is the second largest potato-producing country in the world. Potato fields occupy about 17 percent of the total land in cultivated crops.

The golden nematode can be found in all parts of Poland, but it is more concentrated in the northern, central, western, and southwestern Provinces. A survey carried out by Professor Henryk Sandner in 1961–62 resulted in an estimate of golden nematode incidence of 2.8 percent throughout Poland. It is also estimated that this nematode appears in about 2 percent of Poland's potato fields.

External quarantine regulations control the international movement of potatoes from infected plants, and internal quarantine regulations limit the domestic movement of potatoes from infested areas. Potatoes may be taken out of such areas only for direct use in processing, and the vehicles used for transport must be disinfected.

Resistant potato varieties have not been developed, but two East German potato varieties, Sagitta and Specula, may be suitable for Polish potato growers. There are no known resistance-breaking biotypes in the country. Experiments in the use of nematocides for the control of the nematode have been conducted by the Regional Plant Protection Stations of the Ministry of Agriculture, but the results are described as "rather erratic."

Government regulations forbid the growing of potatoes and tomatoes for 5 years on land known to be infested with the golden nematode. The Regional Plant Protection Stations of the Ministry of Agriculture conduct systematic surveys annually.

Portugal

The golden nematode attacks potatoes and sometimes tomatoes in Portugal. Although its presence in Portugal was already suspected, it was identified for the first time in 1956 in Serra de Nogueira, near Braganca (northeast Portugal) by M. Neves. A more detailed study, by Macara (*26*), was published in "Broteria" in 1963. In 1958, Entrudo Junior made a study of this pest in the region south of Lisbon.

The golden nematode is found mainly in the areas of Beira Alta, Tras-os-Montes, and Estremadura; the latter is near Lisbon and potatoes are grown intensively, sometimes in successive years on the same plot (fig. 66). Information relating to the golden nematode on tomato plants in Portugal is scanty, but it seems that there is danger of a buildup in the nematode population in certain irrigated areas where tomatoes for the canned paste industry are being intensively cultivated, with very short crop rotations or with no rotation at all.

The average annual area growing potatoes and tomatoes is about 100,000 hectares (250,000 acres), but the golden nematode constitutes a problem in only about 10 percent of this area, especially on sandy soils.

There are no specific official regulations in Portugal concerning the golden nematode; the general plant protection regulations are, of course, applicable to this pest. An educational campaign giving advice to the farmers on the

FIGURE 66.—Infested areas in Portugal and Spain.

best way to avoid damages to the crops by the golden nematode has, however, been implemented through the agricultural extension service.

The Plant Protection Service has tried some resistant varieties of potatoes, but they were not found to be satisfactory. Although the Dutch potato variety Amaryl showed some promise, its resistance was later shown to be effective against only one biotype of the several biotypes known to exist in Portugal.

Saarland

The golden nematode was first recorded in Saarland in 1952.

All fields and produce considered to be infested are supervised by the Saarland Plant Protection Service. If one field is found to be infested, the rules apply to all the land of the holding. Use of potatoes from such holdings for seed purposes is prohibited, and these potatoes must be boiled or steamed before being used for the table or for fodder. On fields considered to be infested, potatoes and tomatoes must be grown only once in 3 years. Of plots under 1,000 meters (or parts thereof if used by different owners) not more than one-third can be planted to potatoes or tomatoes, to allow for proper rotation. On land that the Plant Protection Service considers to be heavily infested, the growing of potatoes or tomatoes is prohibited for at least 3 years. If this rule is not obeyed, the crops are destroyed.

Scotland

The golden nematode has been common in Scotland since about 1913. The nematode exists in several locations in the commercial potato-growing area, but there is no organized systematic survey in those areas. Field soil surveys in commercial districts are conducted on a request basis.

Scotland's Plant Protection Service is primarily concerned with protecting the seed-producing areas. Scotland produces most of the seed for England and several other European countries. Careful surveys are conducted in seed-growing districts. For "virus-tested," "foundation," and "stock seed" certificates, a 6-year rotation is required, together with a precrop soil inspection and a crop inspection during the growing season. Soil tests and crop inspections are required for all seed exported. If an infestation is found, the field cannot be used for growing seed potatoes for at least 12 years.

Seed for use within the country is grown on a 6-year rotation basis, together with a growing-crop inspection. If the rotational requirement cannot be met, a soil inspection is necessary. "Washed seed" certificates are available to growers producing seed for domestic purposes, if their crop is found to be infested during the crop inspection. Such potatoes must be washed in an approved washing plant to the satisfaction of an inspector of the Department of Agriculture, Fisheries, and Food.

Spain

The golden nematode was first detected in Spain in 1953 at La Maresma, Province of Barcelona. Presumably, it originated in the imports of foreign seed potatoes. Five Provinces bordering on the Mediterranean coastline, the inland Province of Logroño, and the Canary Island Province of Tenerife are affected by this pest in varying degrees. The geographical points, areas, or districts involved are the following (fig. 66):

Province	*Point, Area, or District*
Alicante	Novelda
Barcelona	La Maresma and lower Llobregat area
Gerona	S.E. tip of Province
Logroño	Santo Domingo de la Calzada
Tarragona	Cambrils
Tenerife (Canary Islands, 1960)	La Orotava
Valencia	Las Siete Villas

No estimate of the overall acreage affected is available. Barcelona is by far the most heavily infested Province. The infestation covers a strip of land in the vicinity of and running parallel to the seaboard; the strip extends along more than one-third of the seaboard of Barcelona Province.

The Spanish Government has issued regulations against the golden nematode. The official action taken includes the creation of a Nematological Section to study and implement plans for the control of potato cultures and import restrictions. The growing of potatoes where the presence of the golden nematode has been verified must be rotated; they cannot be grown more than once every 3 years or more. No host plants of the golden nematode may be cultivated during the intervening period. The cultivation of seed potatoes and certain other plantings on infested land is forbidden.

No resistance-breaking biotypes of the golden nematode have been discovered. Surveys for the golden nematode are being carried out annually.

Sweden

The first discovery of golden nematode in Sweden was made at Högsjöbruk in the western part of Södermanland county (central Sweden) in 1922. In 1928–32 the nematode was found to be relatively widespread in the northwestern part of Skåne (southern Sweden).

The nematode is frequently found in the factory-potato-growing area of southeastern Skåne and Blekinge counties, but it is also found sporadically throughout Sweden. The nematode is uniformly of biotype A.

The first legislation against this pest was passed in 1932. Growing of potatoes on soil declared as infested was prohibited, and removal of contaminated soil was required in certain instances. When it was found that the parasite had been widely spread and could not be stopped, the legislation was adjusted in 1939 and again in 1962. The law is used primarily to prevent the spread of the parasite to certain areas growing potatoes for special purposes (seed potatoes) and to stop the spread of resistance-breaking biotypes.

Resistant potato varieties, principally of Dutch origin, are available, but their use is generally restricted to factory potatoes. A new Swedish table variety has been developed at the Svalöf Plant Breeding Institute.

The Government has authority under the law to prohibit growing potatoes on land declared as infested. This authority is applied principally to land on which seed potatoes are grown. Seed-potato fields are sampled before the growing and cultivating period. Strict regulations are maintained to see that seed-potato fields are not infested through machinery, tools, bags, and so forth.

The Plant Protection Agency makes continuous surveys and also samples soil from potatoes delivered to starch factories. On infested properties, growers are requested to apply a rotation to potatoes; they are not to grow potatoes more often than every 3 years in southern Sweden and every 4 years in northern parts of the country. Available nematode-resistant varieties of potatoes are recommended for use.

Switzerland

The golden nematode was found in Switzerland in 1958. Areas reported to be infested in Switzerland are located in the Orbe Plain and near Murten. Other locations include the mountainous cantons of Graubunden, Ticino, and Valais. Although 132 hectares (330 acres) in 8 cantons are known to be infested, the infested lands are small plots in high altitude valleys where potatoes for domestic consumption have been grown continuously. The degree of infestation is rated as EPPO code III and IV.

The golden nematode is considered a particularly dangerous pest in Switzerland. Government legislation, dated March 5, 1962, concerning plant protection, set forth regulations for the control of the pest.

Comprehensive surveys in all fields in the seed-potato-growing areas are made. All potentially affected areas are surveyed every 4 years. The surveys are organized by the Plant Protection Department and the Seed Breeding Society. Survey results are evaluated at the national level by the Swiss Seed Breeding Society.

The growing of host crops, seedlings of any kind, and nursery stock is strongly forbidden on infested land for 4, and in some places 8, years. No soil or refuse can be removed from areas under restrictions. In protective zones, host plants must not be grown more often than every 4 years. There is a special prohibition for exporting host crops and root crops that have been grown in a protective zone.

Switzerland is not breeding resistant varieties but obtains resistant potatoes from other foreign sources. Quantities available, however, are not sufficient to meet needs. Resistance-breaking biotypes have been found. Experiments are being conducted for the control of the nematode with nematocides. Through the agricultural extension service, particular emphasis is placed on advising growers to carry out sound crop-rotation practices.

Union of Soviet Socialist Republics

The potato nematode in the U.S.S.R. was first discovered in 1948 in the Lithuanian Republic. The nematode was discovered in Latvia in 1949 and Estonia in 1953 (fig. 67).

Separate and isolated centers of infection of the potato nematode have been discovered in other western regions of the Russian Federated Soviet Socialist Republic, mainly on the personal plots of collective farmers and market gardens of workers. The potato nematode has been discovered in rare instances in the fields of collective farms, state farms, and other government enterprises.

Aggressive biotypes of the potato nematode have not been found in the U.S.S.R.

A quarantine system of the areas infected with the potato nematode was implemented, and the contamination has remained insignificant. In 1965, the contaminated area consisted of 0.04 percent of the total potato area in all categories of farming, and the economic loss from the potato nematode was of no practical significance.

In the U.S.S.R. a broad investigation of potato areas is annually carried out with the purpose of discovering new centers of potato nematode contamination.

The main means of combating potato nematode are quarantine arrangements; namely, control and restriction of transportation of potatoes, fodder roots, onions, and other bulbous plants from areas under quarantine for the potato nematode; strict observance of rotations, prohibition of the raising of potatoes in contaminated sections, and utilization of such sections for the cultivation of crops not damaged by the potato nematode; chemical disinfection of soils in separate and isolated centers of contamination.

Agricultural institutions have carried out scientific research in an effort to find resistant types of potatoes.

United States

(See pp. 3 and 14.)

Yugoslavia

The presence of the pest was recorded in 1964 for the first time in Yugoslavia. The pest was found in two localities near Kranj in Slovania, where 12 fields were infested, and near Fojnica in Bosnia and Hercegovina, where 3 hectares ($7\frac{1}{2}$ acres) were found infested. It is supposed that the attacks in Bosnia-Hercegovina were caused by the seed potatoes used. Six laboratories have been set up for the analysis of soil samples to determine the presence of the pest in different stages. Legislation on the control of eelworms is in preparation.

FIGURE 67.—Infested areas in the U.S.S.R.

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APPENDIX I—WORLD POTATO PRODUCTION

TABLE 5.—*Acreage and production of potatoes in specified countries, average 1960-64 or latest available data*

Continent and country	Acreage	Production
North America:	*1,000 acres*	*Million cwt.*
Canada	295	46.0
Cuba	20	2.5
Mexico	121	7.7
United States	1,382	265.8
Total	1,818	332.0
Europe:		
Austria	415	76.5
Belgium-Luxembourg	182	41.2
Denmark	171	31.6
Finland	190	25.5
France	2,086	312.4
Germany, West	2,351	518.4
Greece	110	11.5
Iceland	3	.2
Ireland	209	42.9
Isle of Man	3	.3
Italy	927	86.1
Jersey	5	1.4
Malta	8	.5
Netherlands	330	86.5
Norway	129	23.8
Portugal	254	23.0
Spain	992	101.8
Sweden	249	34.1
Switzerland	115	31.1
United Kingdom	763	150.5
Total Western Europe	9,492	1,599.3
Czechoslovakia	1,278	130.5
Germany, East	1,821	274.7
Poland	7,062	942.9
Yugoslavia	751	63.6
Bulgaria, Rumania, and Hungary	1,438	113.9
Total Europe	21,842	3,124.9
U.S.S.R.	21,600	1,602.5
Asia:		
Burma	40	1.1
China: Taiwan	5	.4
Cyprus	23	2.9
India	1,013	56.3
Israel	13	2.4
Japan	527	81.3
Jordan	5	.2
Korea, North	363	14.3
Korea Republic	118	9.4
Lebanon	20	1.8
Mongolia	5	.5
Pakistan	175	10.1
Philippines	5	.4
Syria	13	1.1
Turkey	363	37.5
Total	2,688	219.7

TABLE 5.—*Acreage and production of potatoes in specified countries, average 1960–64 or latest available data*—Continued

Continent and country	Acreage	Production
	1,000 acres	*Million cwt.*
South America:		
Argentina	453	35.5
Bolivia	283	15.9
Brazil	496	25.4
Chile	212	16.7
Colombia	328	19.5
Ecuador	93	7.2
Paraguay	5	.2
Peru	575	27.2
Uruguay	63	2.2
Venezuela	36	2.5
Total	2,544	152.3
Africa:		
Algeria	75	5.4
Congo	8	.2
Ethiopia	70	3.0
Kenya	133	4.3
Libya	5	.4
Madagascar	40	1.5
Mauritius	3	.1
Morocco	63	5.0
Mozambique	5	.2
Ruanda-Urundi	43	2.2
South Africa	128	9.0
Tunisia	13	1.7
United Arab Republic	58	8.3
Total	644	41.3
Oceania:		
Australia	103	12.6
New Zealand	30	5.5
Total	133	18.1
Grand total	51,269	5,490.8

APPENDIX II—INTENSITY OF INFESTATION

The code numbers for various levels of infestation intensity, as laid down at the EPPO International Conference on Potato Root Eelworm at Wageningen, Netherlands, 1955, are as follows:

CODE No.

I No observation. (This means that no investigation has been made.)

II Free from infestation, as ascertained by—
- a. Standard sampling and laboratory analysis;
- b. Root examination;
- c. Appearance of crop. (In this case, however, the report has little value, for soil may be infested for several years before disease symptoms appear in the crop, and other factors, even other nematodes, may cause the same symptoms above ground.)

III Slight infestation, that is, 1–2 cysts per 200 cc. of soil in sampling, but no weak spots or other field symptoms.

IV Moderate infestation, that is, several (more than 2 but less than 50) cysts per 200 cc., serious loss of crop, or both.

V Heavy infestation, that is, many (more than 50) cysts per 200 cc., serious loss of crop, or both.

APPENDIX III—SOIL SAMPLING FOR POTATO ROOT EELWORM

To sample soil efficiently for potato root eelworm, you need an accurate sampling technique. It is essential to take representative samples, to process the samples so that the cysts therein can be found, to avoid mixing up the samples, and to have sufficient staff available to handle a satisfactory number of samples.

The accuracy of the method depends on a number of factors, including the number of eelworms present in the field, their distribution, the number of points sampled in the field, and the subsequent laboratory handling of the composite field sample. Rather different methods of soil sampling are used in the Netherlands and the United Kingdom, but they appear to result in similar accuracy. In both countries field sampling is carried to a stage where a marked increase in accuracy could not be achieved even by a very large increase in the intensity of sampling.

The most accurate methods are needed in connection with export and certain certification schemes. Less intensive methods are frequently suitable for purely advisory purposes.

The United Kingdom Method

The United Kingdom method consists in making a number of soil borings 6 to 8 inches (15 to 20 cm.) deep with an auger 1.5 in. (37 mm.) in diameter, or other similar tool, at random over the area being sampled. For plants for export purposes 25 such borings are taken from areas up to ½ acre (1/5 ha.), 50 from areas of from ½ to 2 acres (1/5 to 4/5 ha.) and 5 extra borings for each additional acre (2/5 ha.). Additional samples are taken from places where plants to be exported are growing, from glasshouses, loam heaps, and any ground under suspicion. The borings are bulked and taken to the laboratory where the soil is air dried and thoroughly mixed. Two subsamples of 250 g. are taken and their cyst content estimated by a flotation technique.

The Dutch Method

In the Dutch method, a special tool is used for routine sampling. The tool is designed so that 50 prods with it will extract approximately 250 cc. of moist soil, which will make about 200 cc. of dried soil. The usual rate of sampling is 50 prods per hectare, but for special purposes this is increased to 50 prods per ⅓ hectare (about 0.8 acre). The whole sample is air dried and examined in the laboratory by flotation. Special attention is given to the entrances to fields and clamp sites.

Comparison of the Two Methods

The methods differ in the much larger quantity of soil taken from each field in the United Kingdom, in the depth sampled, and in the amount of handling required in the laboratory. As they appear to be comparable in accuracy, there is no technical reason for preferring one to the other, and the Dutch method is simpler.

It is therefore recommended that for survey work a sample should represent not more than one hectare; that it should consist of at least 50 borings or prods; and that at least 200 cc. of air-dried soil should be examined. Under certain circumstances, it is desirable to decrease the maximum acreage covered by the sample. For example, exporting nurseries and areas under suspicion should be sampled 3 to 10 times as intensively as other areas.

Details of equipment and technique should be left to the country concerned, provided that the results are comparable with those obtained with the techniques mentioned above.

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